

PLANT GROWTH

by L. EDWIN YOCUM

Professor of Botany, The George Washington University

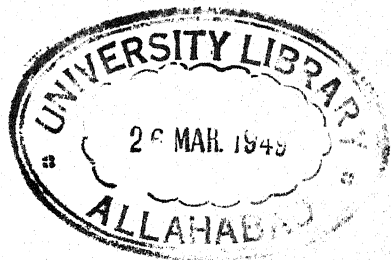
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PREFACE

This book has been written in an attempt to bring together the knowledge necessary to answer (as far as possible) the many technical questions which the plant lover may ask about growing plants. It is an attempt to make clear the "how and why" of plant growth. The principles of the laws of nature as applied to plants growing in the soil are stressed. Many of the newer theories used in plant culture are described; others, not so well established, are suggested as possible future developments. The illustrative material has been selected, when possible, because it is found around most homes, and can be examined by the reader.

The privilege of using numerous illustrations, as acknowledged in each case, has been highly valued. The careful work of Mrs. Marian Manning in making the original photographs is deeply appreciated.

The author is happy to thank Dr. R. F. Griggs and Dr. Mary Reid for frequent encouragement and suggestions during the preparation of the manuscript. For the suggestions and the improvement of the chapters on plant breeding he expresses his heartfelt appreciation to Dr. and Mrs. Jack R. Harlan. The author is deeply indebted to his many teachers, students, and associates who have helped him to get the necessary knowledge to attempt a work of this kind.

The critical reading of the manuscript and the many helpful suggestions of my wife, Mildred Yocum, are most deeply appreciated.

L. EDWIN YOCUM



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Chapter One

INTRODUCTION

Recreation must be a pleasure in order to give the most valuable relaxation from the daily business routine. The growing plant provides interest and pleasure for those who grow plants as a hobby or in their "Victory" gardens, because both their minds and their bodies are stimulated. This kind of activity is only the summer recreation of some but the year-round interest of many who during the winter read of new plants and new cultural methods and plan ways of improving on the result of their past season's effort. The seed catalogues offer the beginner general guidance in plant culture but as his knowledge grows he is soon beyond the catalogue stage.

The many questions of friends concerning their growing plants stimulated the author to select what seems to be the fundamental knowledge necessary for the solving of their problems. These people are already growing plants successfully, but they are interested in the requirements of plants and the best cultural methods for meeting them. Our scientific age has been an important stimulus to study the basic reasons for the many plant responses. The following is an introductory survey of the point of view and the material covered in these various fields.

To deal with the laws of nature as they govern the growth of plants requires a wide range of knowledge because growth involves the response of many activities of all parts of the plant to soil, water, temperature and air, as well as to the plant's enemies and other factors of its surroundings. This response of plants to their environment has been developed to the extent that it is known as the science of "Ecology."

The results of discovery are cumulative and no attempt will be made to trace the development of our knowledge of growing plants. The principles involving the chemistry and physics of growth will be explained in terms which will not assume a knowledge of these sciences on the part of the reader. In most cases only the facts pertaining to a particular phenomenon are summarized, but a few brief descriptions are given of some of the more recent discoveries of these facts.

An attempt has been made to present scientific knowledge in a direct and terse manner. If the reader will follow the text illustrations, or better, where possible, study his plants in the light of the text descriptions, he should find this method sufficiently detailed. Considerable thought has been given to presenting clear mental pictures of the structure and the internal work of the plant.

In order to study or converse about the growing plant it is necessary to know the various parts of the seedling described in the next chapter as well as the whole plant in later chapters. Even that inner structure hidden from view because of the size of cells, as described in Chapter 4, may be studied by the aid of the microscope in order to understand its growth and specialization. In fact, it is the influence of the environment of these cell structures which determines their growth and in turn the growth of the whole plant.

The many different kinds of cells found in plants are shown in the illustrations of plant structure. These cells are all inter-connected and carry on their particular functions through the protoplasm, which is a highly complex chemical containing a large quantity of water. This protoplasmic material is living and can grow or increase in quantity by its synthesis from water and the so-called food-making materials absorbed by the plant from the soil and the air.

These detailed structures of the parts of typical plants

are stressed in various chapters to give the reader a clear understanding of the plant, necessary as a basis for the observation and study of the growing plant. These parts should be compared and contrasted in different plants and in many cases described in brief notes for future comparisons. All experiments should be studied carefully and compared with normal or untreated plants. Often important differences may seem doubtful differences until such comparisons can be made. Such careful observation and checking are the final constructive steps necessary for the most successful improvement in methods or in plants.

As the fundamentals of plant life are learned it becomes easier to understand fertilizer requirements, as described in Chapter 22, and to diagnose the plant's lack of certain food-making materials and of water for its absorbing roots. Water and fertilizers applied by gardeners using that knowledge have paid pleasing dividends in many "Victory" gardens.

The soil, as outlined in Chapters 7 and 21, is such a common material that it is usually thought of as only a source of water and of fertilizers for the plant. If that were the case, the use of water solutions or water gardening would be simplified. We speak of a good or of a poor soil, because of the plant's response not only to the water and the minerals, but to the many other components of a good soil, such as air, soil structure, and the life of the soil.

Plants are often compared to factories in their activities. They take their raw materials from the earth and the atmosphere and by using the sun's energy for power, convert them into many useful products. Sugars and starches are the first products, but these can be reconverted into any number of substances found in the plant, most of which are useful to man. The cell walls become wood, the proteins are useful for food or to make the parts of the seed, the coloring matters make the leaves green and give color to the flowers

and fruit. We cannot enumerate the many uses we find for these manufactured products of the plant. We must, however, bear in mind that as in any factory a balance is maintained between the supply of raw material and the finished products.

Hybridizing of plants is becoming so important and so popular that two extensive chapters are included to give a scientific background and a working knowledge of the common methods. Of course the factual information covered in many other parts of the book is fundamental to the study of hybridizing. For example, the sections on chromosomes, flower structure, and seed development should be carefully studied before attempting any such plant improvement.

Only a small portion of all the important and necessary knowledge for the reader who wants to know all about plant growth can be included in a single volume. It is hoped that with the illustrations and text diagrams and with suggestions about plants familiar to many people this may become useful as a work book, with help from the addition of selected references at the end of most of the chapters. The author has attempted to list representative titles, but realizes that many other equally important ones might have been added. References of a general nature, such as the various textbooks of botany, review articles in special fields and research articles in small parts of special fields are included from which the reader will be able to select the ones best suited to his needs.

Many of the illustrations were selected to show more detail than described in this book, in order that they might serve as an aid in terminology in more intensive reading. The illustrations should be found valuable aids in helping the reader to build a clearer mental picture of plant structure. The work of the plant can be understood and enjoyed only as it is considered in relation to structure.

Finally, in order to give further aid in the study of the growing plant, a glossary of difficult terms has been included.

It is necessary to use at least a limited terminology to describe the subjects properly, but it has been restricted as much as seemed possible. The glossary also gives a reference to the further description and use of each term.

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Chapter Two

SEEDS AND SEEDLINGS

A seed is a potential plant living in the seed coat with stored food and awaiting favorable conditions of moisture and temperature for further growth. Seeds have many remarkable characteristics which have enabled them to reproduce their kind through many past ages after withstanding conditions unfavorable to the mature plant. These characteristics, in many cases, have been and are important to the survival of the species. Many, but not all, cultivated seeds retain these characteristics, and this fact must be considered in their culture. Those that have lost some of these old habits under cultivation cannot survive among the wild conditions if they escape from the garden and the care of man. The breeding of plants for domestic use has made many changes in the seeds as well as in other parts of the plant. Seeds, such as beans, which are used for food have been developed to increase the amount of plant food stored in them; other seeds have been improved by the development of strains that germinate quickly and in a uniform time.

Most mature seeds of wild plants are in a resting condition for varying lengths of time during which they are unable to germinate. Seeds of some cultivated plants such as petunia and portulaca fall to the ground during the summer and remain dormant until spring; others, such as larkspur, are dormant for a short period after which they grow a good tap root system and a rosette of leaves in the late summer; but the seeds of many cultivated plants have no resting period or one of only a few days. This lack of a rest period explains the sprouting of farm crops when unfavorable weather occurs at harvest time. Since seeds are capable

of germination, it is necessary to store them under conditions unfavorable to growth activities until planting. Cool, dry storage is advisable for most seeds.

The seed coat consists of several layers of tough-walled cells. In some families, notably sunflower, zinnia (Fig. 20, C and E) and grass, a single seed grows in an ovary (see Fig. 1 showing it as fruit coat) the wall of which is so closely

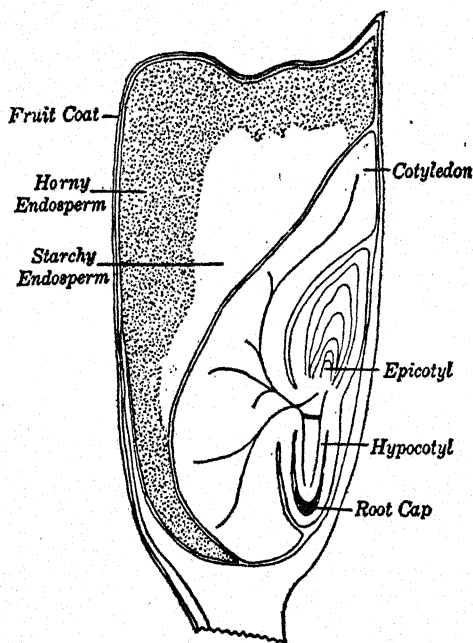


FIG. 1. Lengthwise section of fruit (grain) of corn showing the embryo with its parts embedded in the endosperm. (After Smith *et al.*, *A Textbook of General Botany*. By permission of The Macmillan Company, publishers.)

attached to the seed coat that they appear to be one. The gardener calls these seeds, but since the ovary wall is included, the botanist speaks of them as fruits. Hence we plant the fruits of corn and sunflower. The relation of seeds to the ovary and the fruit is further explained in Chapter 17.

The seed coat is a protection against mechanical injury, and in a small degree against moisture loss or absorption. Some seeds, notably those of the clover family, have a nar-

row layer in the outer row of cells, which is impervious to water. A few other seeds have seed coats so tough that the seedling cannot break it to escape. If seeds do not swell with a few hours of soaking it is best to break the seed coat, since it so frequently is a cause of delayed germination. Some seeds of wild plants have their germination delayed several years by their naturally tough seed coats, and thereby some of them may germinate at a more fortunate time for their survival than if all germinated at the same time.

The hilum is the scar on the seed coat which was caused by the attachment of the seed to the ovary, and through which the food passed to the seed. This is very obvious in bean seeds (Fig. 2). The micropyle (Fig. 2) is a small pin-

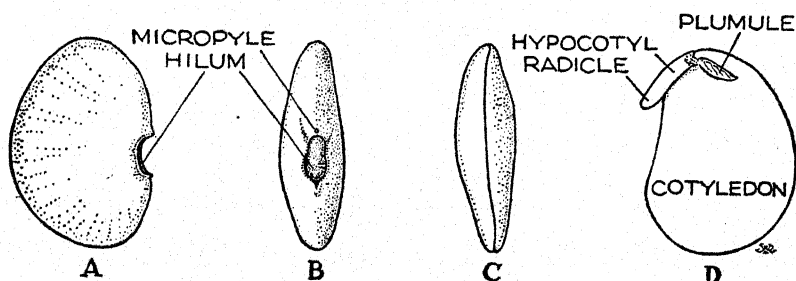


FIG. 2. Seed of bean. A, side view. B, as seen from inner (attached) edge. C, from the outer edge. D, embryo; seed coat and 1 cotyledon removed.

point pore below the hilum through which the pollen tube entered and toward which the radicle points inside the seed coat.

Every seed must grow from a fertilized ovule in a flower, as described in more detail in Chapter 17. In the common garden pea each flower has an ovary which will develop into the mature pod. Each pea or seed in the flowering stage was only a small ovule consisting of a mass of cells with a single female sex cell. A pollen grain must fall on the stigma and grow the pollen tube bearing two male sex cells, one of which must unite with the female sex cell of each ovule. This is called fertilization and results in a powerful stimulation for

the growth of the ovary and seed. These two sex cells will become the embryo plant of the seed. If an egg cell remains unfertilized, the ovule will remain about as large as the head of a pin while the ovary will soon die and wither if none of its ovules are fertilized.

The embryo of the seed is the resting or dormant stage of the small living plant within the seed. It consists of (1) a radicle pointing toward the micropyle, which emerges first in germination and develops into the root system of the plant; (2) one or more cotyledons; and (3) the plumule which is a group of folded leaves so small that it is seen with

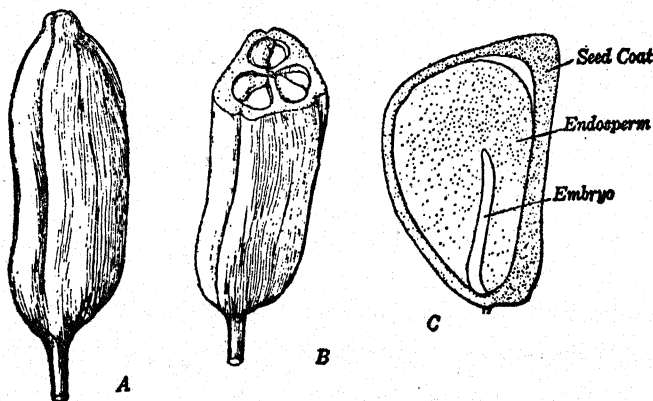


FIG. 3. Iris. A, B, surface view and cross section of the fruit. C, lengthwise section of a seed. (After Smith *et al.*, A Textbook of General Botany. By permission of The Macmillan Company, publishers.)

difficulty between the cotyledons just above (4) the epicotyl. The plumule produces the shoot when the seed germinates (Figs. 1 and 2, D). It will be noted that in many seedlings the first leaves above the cotyledons differ in size and shape from those appearing later. Many legumes have simple leaves above the cotyledons and all later ones are compound.

The largest part of the seed is that which contains the supply of stored food for the growth of the seedling until it is large enough to make food. In albuminous seeds, such as

castor-bean, iris (Fig. 3) and corn (Fig. 1), the food is located in a region called the endosperm, which is the product of the polar bodies of the ovule and the second sperm. In exalbuminous seeds, such as the common bean, the food is stored in the two cotyledons (Fig. 2). These fleshy bodies, readily distinguishable in cooked beans, are the first structures to appear above the ground in germination.

Plants are classified according to the number of cotyledons or seed leaves of the embryo. Those growing from seeds with one cotyledon, such as corn, are called monocotyledons; those growing from seeds with two cotyledons are called dicotyledons. The cone-bearing trees, such as pines, bear seeds with more cotyledons, usually from five to eleven.

Monocotyledonous seeds of the grass type have a small embryo and a large endosperm. The embryo is only about 8 per cent of the wheat grain, but it is a little larger in corn. The epithelium (shown as a double line in Fig. 1), is a single layer of cells between the embryo and the endosperm, which secretes enzymes to digest the stored food when conditions are favorable for germination. The iris type has a small embryo (Fig. 3, C) embedded in the endosperm. Such monocotyledonous seeds as the grasses and orchids are so small that their structures are difficult to see and their germination is poor because the supply of stored food is so limited.

The best seeds should always be used by the gardener, because the difference in cost is so small when compared with the difference in the plants grown from the best and from inferior seeds. Select well-bred seeds of good varieties from reliable seedsmen. Home-collected seeds of many species produce inferior plants, largely because of cross pollination. For those who are interested in developing their own seeds suggestions for artificial pollination are described in Chapter 18.

The vitality or viability of a seed, which is its internal capacity to germinate and grow under favorable conditions,

is affected by the conditions under which the seed is developed, the age of the seed and the conditions of storage. Seeds developed under unfavorable conditions will produce inferior plants. Immature seeds lack vitality because of insufficient stored food, and seeds past their maturity lose vitality with increasing age. High moisture content and high temperatures in storage increase respiration and lower vitality.

Longevity refers to the length of time a seed can retain its vitality in storage. The longest record of longevity in seeds is held by Indian lotus, which germinated after being buried in peat for two hundred years. Many seeds remain viable for ten or more years, but most of our garden seeds have a longevity of less than five years. The facts regarding the age and germination after thousands of years of seeds from Egyptian tombs are too fragmentary to be credited here.

The seed uses the stored food while it develops into a seedling by first sending a radicle or primary root into the soil and later the plumule or shoot into the air (Figs. 4 and 5). The seed should be planted deep enough to anchor it while the primary root enters the soil, otherwise, the root will push the seed out of the soil instead of itself going deeper into the soil. If the seed is planted too deep, energy is wasted pushing the shoot through the soil, so that in extreme cases it may be unable to penetrate. The early root growth is much more rapid than the shoot growth. This enables the root to absorb water and mineral salts for the rapid growth of the entire plant which follows.

Since the seed must furnish all the food for the early growth of the seedling, it is not surprising to find a well-balanced combination of starches, proteins, minerals, enzymes and vitamins in storage form. Frequently minerals are in larger amounts at the seed surfaces, but the enzymes and vitamins are more concentrated in the embryo.

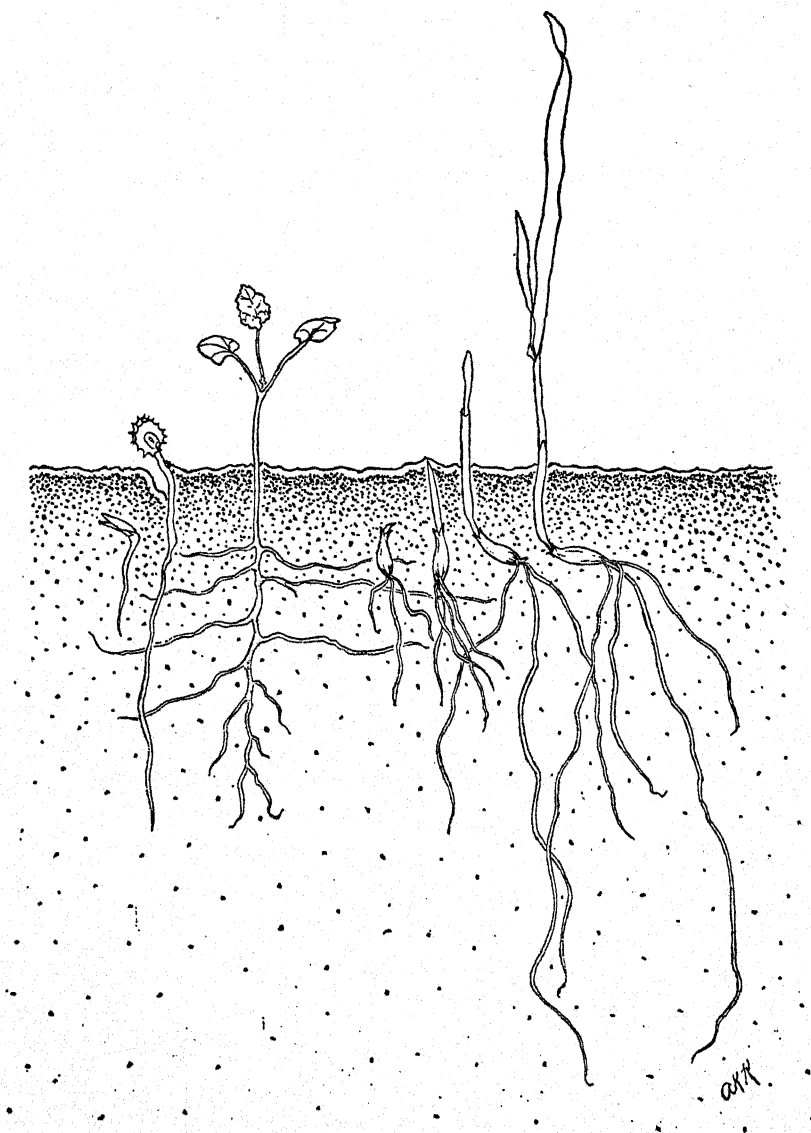


FIG. 4. Seedlings of hollyhock (left). The smallest seedling shows the early root growth, the next the cotyledons protecting the shoot as it pushed through the ground, and the largest shows the two cotyledons and the shoot between them. Oats (right). The pointed coleoptile pushes through the soil, after which it splits and the true shoot emerges ($2/3$ natural size). (By Antoinette K. Ketner.)

The growth of the seedling is oriented by its response to gravity, therefore it is not necessary to give consideration to

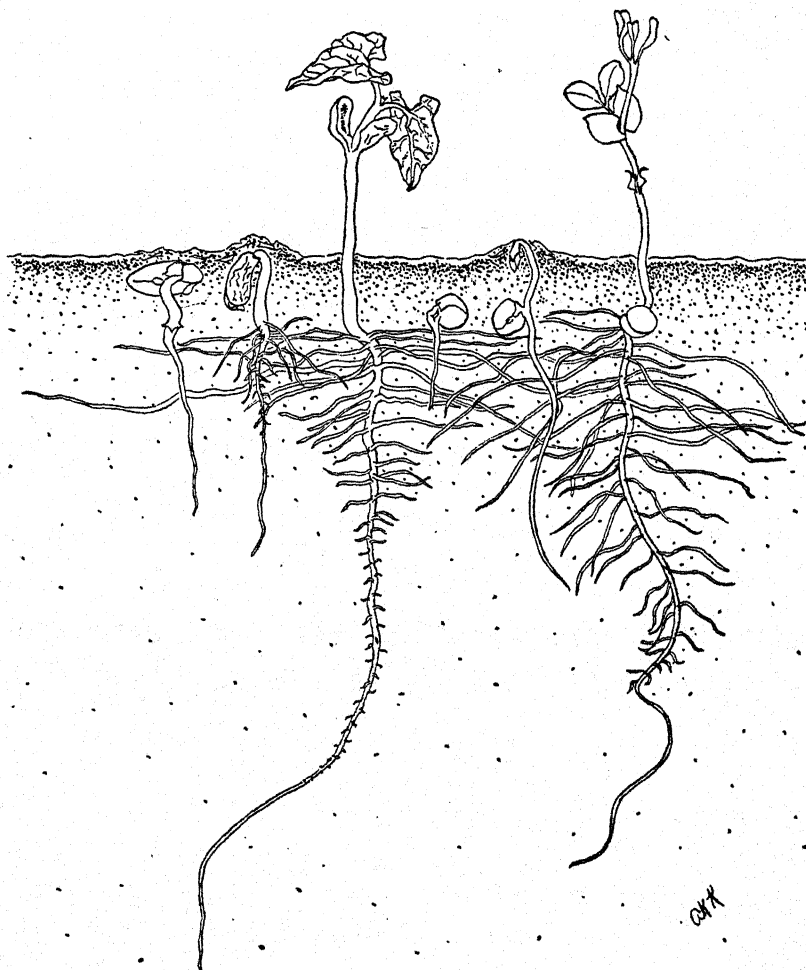


FIG. 5. Seedlings of bean (left). The cotyledons protect the shoot as it comes through the soil. The largest one shows a pronounced primary root. Pea (right). The cotyledons remain where they were planted, but the shoot pushes through the soil in a bent position protecting the growing point ($\frac{1}{2}$ natural size). (By Antoinette K. Ketner.)

the position of a planted seed. The radicle will even make a sharp bend to grow downward if the seed is so placed that it points upward. The same is true of the plumule. This

direction of growth has recently been found to be due to the growth hormones, which are discussed in Chapter 20.

Soil frequently forms a crust on the surface through which the shoot must force its way. Several methods of protecting the tender growing cells may be observed, as shown in figures 4 and 5. The common bean and hollyhock push the cotyledons through the soil by the elongation of the hypocotyl, with a sharp bend at the top, before the tender plumule emerges. The garden pea pushes the plumule upward in a shepherd's crook position protecting the growing tip, while the cotyledons remain where the seed was planted. In the grasses, as is illustrated by oats, the cotyledon remains in the endosperm while a tough sheath, called the coleoptile, fits over the end of the growing shoot until it emerges, after which the sheath splits to free the plumule. Most albuminous seeds other than the grasses germinate similarly to the common bean and bring the endosperm into the air with the cotyledons before the plumule appears.

The primary root grows secondary roots and in most cases is the beginning of the root system of the mature plant. The tap root is a continuation of the radicle in most cases. In the grasses a permanent root system develops later at a uniform distance from the soil surface regardless of the depth of planting. When the cotyledons come above the ground the hypocotyl, meaning the part which is below the cotyledon, has a structure unlike the older shoot. The cotyledons of some plants, such as the tomato, shown in the photograph (Plate I), become green, grow and make food, but many others lose their food to the growing plant and gradually shrivel and later fall off. The seedling stage is considered past when the plant no longer depends on food supplied from that stored in the seed.

Chapter Three

GERMINATION OF SEEDS

The optimum conditions for germination vary for different species of seeds, but even for a given species of seeds the conditions may vary over a wide range, as described later under soil moisture and temperature. The gardener always strives to reach the optimum for each kind of seed. After selecting good seeds, the following should always be considered: the best moisture condition, the best temperature, and adequate air for the oxygen supply.

The seed must absorb a large amount of moisture, often double its dry weight. A soil which is so dry that it supplies water to the seeds more slowly than a moist soil, retards their germination. Since most seed coats are permeable to water on all surfaces they should have the moist soil pressed tightly against them at all points when they are planted. For this reason the gardener often walks on the planted row. Other methods of compacting the soil are: tamping with a hoe or board, or with a horse-drawn roller.

Soaking seeds in water before planting is not only unnecessary but actually may be harmful in that it reduces the germination vigor because of the loss of mineral salts to the water and the lack of oxygen which is essential for respiration. Water is absorbed by seeds with so great a force that it is readily taken from soil. If a thin-walled glass bottle is filled with dry peas and water is added, they will absorb the water and swell with a force great enough to break the bottle. Other experiments have shown that water enters dry seeds against a force of several hundred pounds per square inch when they are in soil with less than the optimum water content. This accounts for the rapid and advantageous absorption direct from the soil.

The temperature of the soil at planting time plays the most important part in the speed of germination of many seeds because the rate of water absorption and of enzyme activity like all other molecular and chemical actions are regulated by temperature. Because of the difference in the optimum temperature for the enzyme activity, some seeds, such as peas, germinate better at low temperatures than other seeds, such as zinnias. At a temperature below 40° F. it requires six to ten times as long for red clover to germinate as at the optimum temperature of about 60° F.

Since all the passages through the seed coat are extremely small and are filled with water, the oxygen for respiration must be dissolved in the soil water before it can enter the seed. When the moist soil is packed around the seed, as explained above, the soil moisture comes in contact with the moisture in the passages of the seed coat and the oxygen can enter the seed through these water passageways. The air spaces in the soil supply the oxygen to the water as it is absorbed by the seed. Since the seed needs both oxygen and water, the importance of an optimum amount of each is evident. However, excessive rain causes an oxygen deficiency because as the water content of the soil increases, the soil air decreases. Seeds may fail entirely to germinate in an excessively wet soil, also the growth of plants is retarded and their leaves turn yellow with excessive rain. A loose porous soil supplies air most effectively. Chapter 7 describes soil conditions more fully.

Seeds planted nearest to the optimum conditions will germinate quickest. Planting time must be adjusted to the conditions of the soil and temperature, but early planted seeds frequently produce earlier plants than those planted under more favorable conditions even though their rate of germination and growth was slow. The minimum temperature for germination of peas is under 40° F. while for cucumber it is above 60° F., hence peas may be planted two or

three months before cucumbers and zinnias. Personal experience and suggestions from seed catalogues are good guides for the observant gardener in determining the best planting conditions.

The physiology within the seed resulting in germination is regulated by three external conditions: temperature, moisture, and oxygen. Since food is stored for early growth only water and oxygen must be absorbed. The following changes take place simultaneously during germination in a closely connected and related way. (1) Water diffusing through the seed causes it to swell and weaken the seed coat. (2) The enzymes become activated and dissolved in the water and diffused to the stored food. The enzymes, or the substances which become enzymes, appear to be in the dry seeds and sometimes in localized areas; for example, the enzymes of the corn seed are in the epithelial layer (Fig. 1). The rate of enzyme action increases rapidly with an increase in temperature, in fact in many cases an increase of 18° F. will double the action of the enzyme. With a favorable temperature, the enzyme actions in a germinating seedling appear to supply soluble food materials, as indicated by their abundance, more rapidly than they can be used. (3) The stored food of the endosperm or cotyledons is made soluble and diffusible by the enzymes: large molecules of starch, insoluble in water, are broken into smaller molecules of water-soluble sugar; molecules of fats are converted into fatty acids; and molecules of proteins into amino acids. (4) The food diffuses to the growing parts of the embryo. (5) Part of the food is used in respiration or plant oxidation¹ to supply the embryo with energy. (6) Part of the food is used to

¹ The process of respiration illustrates the kind of oxidation taking place in plants and is the reason for their need of oxygen in the germination process. This can be tested by putting a quantity of soaked seeds in a thermos bottle and measuring the increased temperature at the end of one or two days. The experiment is more successful if a small bottle of sodium or potassium hydroxide solution is placed in the bottom of the thermos bottle to absorb the carbon dioxide from the respiring seeds.

build more protoplasm and to make more cells, thus increasing the size of the embryo. The rate at which these numerous activities in a germinating seed proceed in a coordinated manner depends in several ways on the conditions of the environment with regard to temperature, moisture, and oxygen, any one of which may limit the rate of development.

Since the stored food is being used for respiration and growth by the young embryo, the seedling will lose in dry weight until it is able to carry on photosynthesis in the new leaves to make food at least as fast as it is being used. A young seedling several times the size of the seed may have a dry weight of less than 60 per cent of the original seed. This stage in the life of the plant is a critical one because it has not developed protective tissues against insects or loss of moisture and has a small reserve of food. Wheat has used more than 80 per cent of its stored food during the first nine days of germination, after which it is largely dependent on food from photosynthesis. If seeds are planted too deeply or if some other condition is unfavorable for rapid germination, they may exhaust the stored food before they are able to synthesize it fast enough for vigorous growth.

The fact that seedlings will grow slowly or may die because of lack of food may be employed in a number of ways to control weeds. They are easily pulled at the seedling stage because of the small root system, or they can be covered and soon starve to death. Weed seedlings will be less likely to establish themselves in a lawn where the grass is cut two inches long than in one where it is cut less than an inch long, because the additional shade retards photosynthesis, further weakening the young weeds when they are deficient in food.

If two sets of seeds are planted in soil and given comparable conditions except that one set is kept in the dark and the other in the light, the seedlings in the dark will "grow" at an astonishing rate. They appear to be growing faster than those in the light, but if they are examined more closely it

will be seen that the stems alone are making rapid growth. They are becoming etiolated. The internodes will be long but perhaps there will be no more of them. The stem will be smaller in thickness and will be softer in texture. The leaves will be small, with long petioles. If the roots are examined, those of the plants grown in the dark will be found to be smaller and poorly branched in contrast with those of the plants grown in the light. This difference in the character of growth is believed to be due to the effect of light on a growth-regulating hormone. The plants grown in the dark are heavier due to more water in the larger cells, but if the dry weights of the plants are determined, it will be found that the larger plant, grown in the dark, has not produced as much plant material as the plant which was grown in the light. The photograph (Plate XV) showing pea and radish seedlings, and the table on page 181 illustrate what happens under these conditions.

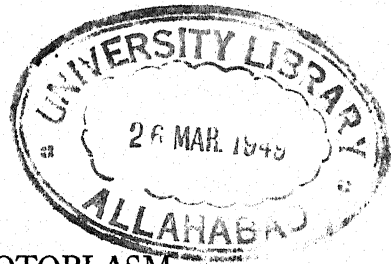
Some mineral salts are absorbed by the very young seedling, but the amount is negligible in comparison with the weight of the stored food or later with the weight of the manufactured foods. A favorable supply of mineral salts in the soil, however, will stimulate growth very early in the seedling development. If a quickly available nitrogen fertilizer is applied, it may increase the early growth of the shoot, and cause the plant to be a little earlier in its flowering and fruiting.

Most seeds should be planted as shallow as possible in order that they may get an abundance of oxygen, but deep enough to give them constant moisture. While it is easier to plant them too deep than too shallow, a good rule is to try to cover them with a depth of soil four to six times the diameter of the seed. A few seeds, such as some lawn grass seed, need a little light to germinate best, and must, therefore, be covered very little if at all. If the soil around young seedlings becomes so dry that water cannot enter the seedling, it will

soon die because of the destruction of the protoplasm. For this reason watering is essential until the root is deep enough in the soil to have a more uniform water supply. The gardener can expect many kinds of seeds to come through the ground in about four days if the moisture and temperature are optimum, but others may require two weeks or longer even under ideal conditions. Many seed catalogues give a table of dates to plant and the time required for germination.

Seedsmen must have their seeds tested for purity and germination before selling them, but seeds that have been kept for some time should be tested before planting. A simple method consists of using a dinner plate with two pieces of cloth of coarse texture well soaked in water and wrung until moderately wet, between which the seeds are placed where they will absorb enough water. They should be covered with a piece of glass or a second plate to prevent the loss of moisture, and placed in a favorable temperature. The number of seeds should be large enough to give an accurate test. They should be examined at two-day intervals and the seedlings removed as they germinate. The cloths and plates should be put in boiling water in order to kill molds that accumulate before being used again for testing.

Healthy seedlings that will develop into plants with strong stems and well-branched root systems may be expected from carefully selected seed planted where there is plenty of light in well-prepared soil of relatively low moisture and medium nitrogen content. These conditions make strong seedlings which are a necessary foundation for a successful garden.



Chapter Four

CELL STRUCTURE AND PROTOPLASM

The unit of life is the cell, and one or more of these units constitute the structure of plants and animals.

Although widely varied in size and shape, most cells are microscopic, somewhat elongated and box-like in structure, with each of their several sides attached to another cell somewhat in the fashion of the cells of a honey-comb. The cells in most tissues are so small that in cross section one hundred to one thousand are found per linear inch or ten thousand to more than a million per square inch. Most of them fit together in a definitely organized pattern that gives great strength to a tissue while in some tissues of the plant large cavities occur between and at the corners of the cells. The complexity of the plant is the result of the many parts and of the many different cells of which it is made. The actual number of cells in a bean, petunia or grass plant is not so important if we remember they are so numerous that they have never been counted, but the various kinds have been very well studied and described. It has been said that the surface of the leaf has more than a million radial cell walls per square inch to support it. If we look at a leaf with a mental picture of its cellular structure as shown in the diagrammatic view of the cells (Fig. 15), highly magnified, we get an idea of the nature of the cell arrangement; those in the blade at the right have large cavities between them while those at the left in the midrib fit closely. Further descriptions of cell arrangement and size will be found in the chapters on the root and stem, but the details of individual cells are too small to be shown here.

As shown in the resting stage of Figure 6, a cell has three distinct parts: the cell wall, the protoplasm, and the non-

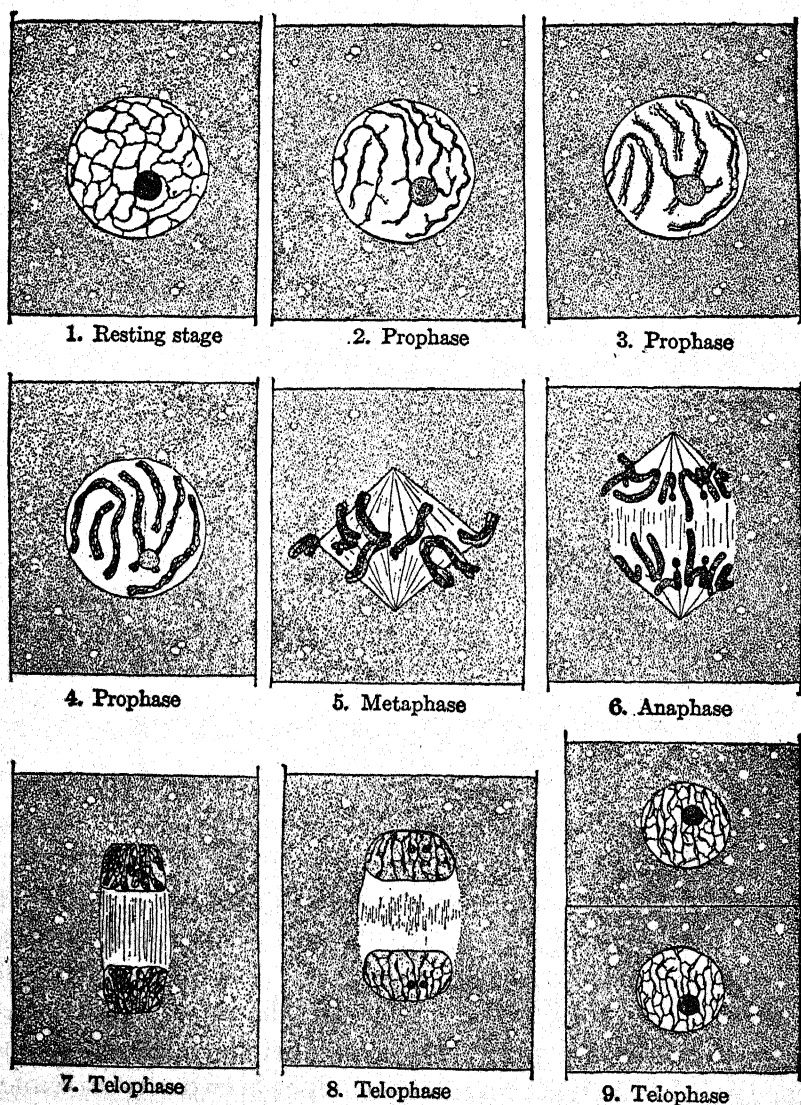


FIG. 6. Semidiagrammatic representation of cell division in meristematic cells of a plant, showing nuclear division by mitosis. 1, Cell before division begins, with the nucleus in the resting condition. The chromatin threads form a network. 2, 3, 4, Prophase of nuclear division. In 2 and 3 the double nature of the chromatin threads is apparent. In 4 the chromosomes are distinct and their doubleness still apparent. 5, Metaphase of nuclear division; nucleolus and nuclear membrane have disappeared, the spindle has been formed, the chromosomes lie in or near the equator of the spindle, and some of the fibers are attached to the chromosomes. 6, Anaphase. Movement of

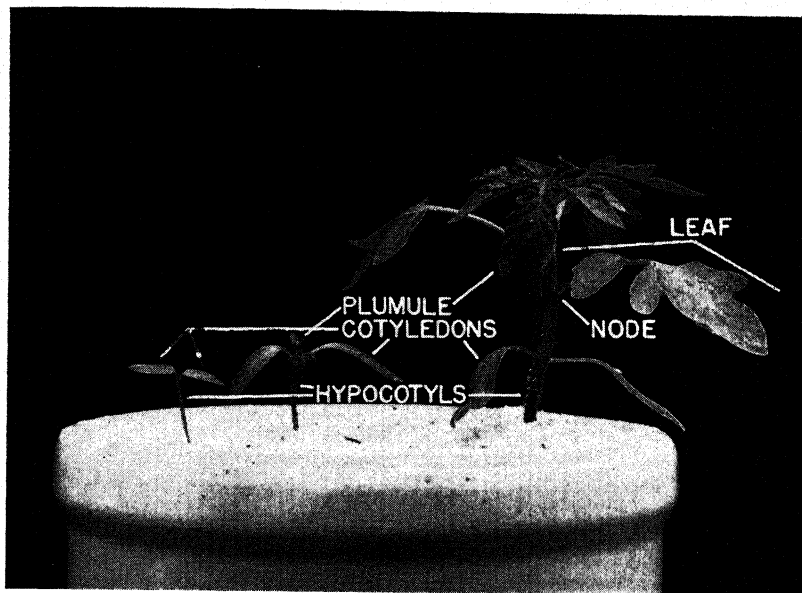


PLATE I. Three stages in the growth of tomato seedlings to show the development of the cotyledons and plumule.

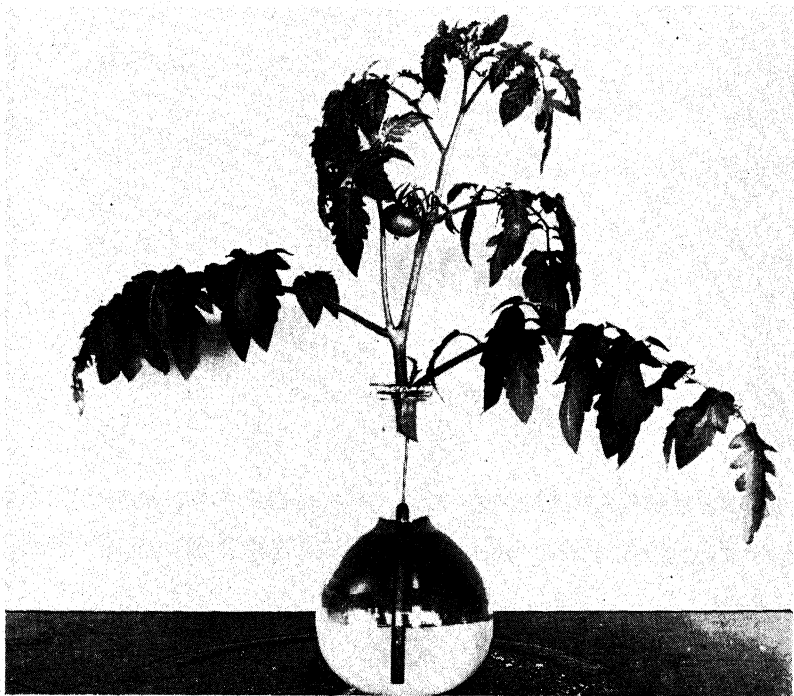


PLATE II. A branch of a tomato plant showing compound leaves with a small growing bud at the lowest leaf and the bud on the next leaf grown into a branch.

living contents. The cell wall, indicated by the border line, is a non-living secretion of the protoplasm, most of which is cellulose, a substance similar to starch in its composition. This stretches as the cell increases in size, and becomes thickened with the age of the cell by addition from the protoplasm. Recent studies have shown the wall to be made of an extremely fine network of needle-like crystals. Most important is the strength and shape the cell walls give to a plant. The main portion of the cell, the protoplasm, is the living, nearly transparent material which may be further divided into cytoplasm and a spherical more dense portion with a net-like structure, the nucleus. The protoplasm is a complicated chemical compound made up of carbohydrates, proteins, water, fatty substances, and simple compounds of mineral salts so organized as to have the characteristics of life. The synthesis of the protoplasm is an important function of growth similar in all organisms, so far as is known at present. Next to water, protein is the most abundant, most variable, and therefore most studied constituent of protoplasm. In addition to the elements carbon, hydrogen, and oxygen, found in carbohydrates and fats, proteins have nitrogen and sulphur, and usually other mineral elements in very small amounts. The non-living often invisible content of the cell, scattered through the protoplasm, is made up largely of solutions of salts, sugars and other food materials. This non-living food matter is usually either in one or more spaces, called vacuoles, near the center of the cell or in many vacuoles scattered throughout the protoplasm. The above is shown in outline form with additional subdivisions.

daughter chromosomes away from the equator of the spindle. 7, 8, 9, Telophase. In 7, daughter chromosomes form two compact masses. 8, Reorganization of resting nuclei begun, the double nuclear threads become apparent, nuclear membrane and nucleolus appear. In 9 the nuclear net is forming and the new cell wall separates the two new cells. (Reprinted by permission from Holman and Robbins' Textbook of General Botany, 4th edition, John Wiley and Sons, Inc., 1938.)

The cell	Cell wall	(Cellulose)
	Protoplasm	<ul style="list-style-type: none"> Cytoplasm (water, proteins, carbohydrates, fats, and mineral salts) Nucleus, which contains the chromatin (similar to cytoplasm, but the protein has a high phosphorus content)
	Non-living content	<ul style="list-style-type: none"> Water solutions of salts, sugars, and other foods Insoluble foods as starches and proteins Wastes

The cell wall varies in thickness with the function of the cell. In some strengthening cells such as those in wood, the cross-sectional area of the wall may be as great as the remainder of the cell. Even succulent vegetables such as asparagus may become woody as the cell walls thicken. Rapid continuous growth produces more desirable vegetables because in rapid growth the cell walls stretch thin as the cell increases in size.

The function of a cell wall is comparable to an automobile tire that resists the expansion of the inner tube, since it resists the expansion of the protoplasm and gives shape to the cells and to the plant. The pressure of the protoplasm against the cell wall often exceeds one hundred pounds per square inch; the air pressure in a tire is from twenty-five to fifty pounds. When excessive loss of water from a plant reduces this protoplasmic pressure against the cell walls to zero, the plant wilts, in other words water pressure prevents wilting.

The portion of protoplasm exclusive of the nucleus is known as cytoplasm. In addition to its complex chemical nature it appears to have very definite structural nature or physical complex. Chemists can analyze protoplasm and tell us its elements, but the physicist has been unable to give us the details of their arrangement, which is generally believed to be the "key" to life. The cytoplasm absorbs and holds water with an enormous force, and the withdrawal of large amounts of water may kill it. An exceedingly thin layer of cytoplasm, with different properties from the rest, lies next to the cell wall and seems to control the substances

that enter and leave the cell. For example, if an uninjured beet is soaked in cold water, the color and the mineral salts will be held in the beet by this layer, but if the cytoplasmic layer is injured, as by heating the water, the color and mineral salts will diffuse from the beet into the water. The green color of plants and most of the other colors are located in special parts of the cytoplasm called plastids. A single cell of a leaf may have several hundred of the green plastids called chloroplasts, named from the pigment chlorophyll. The cells in the leaf diagram of Figure 15 show small numbers of chloroplasts located near the cell walls.

The nucleus is often spoken of as the center of life because cells cannot live without the nucleus. It is believed to control the activities of the cell by its secretions, but this needs further study because of our rapidly growing knowledge in the fields of hormones and of enzymes, and their regulatory power. Since the size of the nucleus of a young growing cell is about 10 per cent of the total cell but decreases with the age and diminishing activity of the cell, it suggests that the nucleus may secrete the above all-important substances as one of its functions. The highest phosphorus content of the cell is in the nucleus. The material of most interest in the nucleus is a protein called chromatin, which in very small granules is scattered, doubtless in an orderly manner, through the nucleus. At the time of cell division these chromatin granules are clearly seen to make larger pieces in an orderly fashion called chromosomes (see 4, 5, and 6 in Fig. 6). Very recently a group of scientists claimed that by proper techniques it may be demonstrated that the chromatin retains its orderly identity at all times.

The number of chromosomes in a cell is always the same for all the cells throughout a plant and is generally uniform for the same species or variety. Many plants, but not all, have had their number of chromosomes determined by actually counting them in highly magnified dividing cells.

The counting of chromosomes is exceedingly difficult because of their small size. A few plant cells have chromosomes large enough to be seen clearly when magnified fifty times, but in many others they are so small that they appear as dust particles when magnified a thousand times. Most of those counted fall within a range of from twelve to twenty-four for each nucleus in the plant cell. In a few plants the phenomenon of polyploidy has occurred naturally, and recently artificial treatment has induced it in many others. Polyploid plants are those which have more chromosomes than is common for the species, often double the number, but always a multiple of the number found in the sex cells. How the identity of chromosomes, and the chromosome content can be maintained and transmitted from generation to generation has been the subject of much study. Cell division gives an idea of the mechanics of chromosome continuity but the physiology of control remains a secret.

Chromosomes, believed to be that part of the sex cells which transmits and gives to new organisms their characteristics, are so important that their structure and behavior have been the subject of extensive study. From this study a body of facts has been deduced and certain hypothetical theories have been projected, some of which are supported by convincing evidence and are used in the study of inheritance. Chromosomes are found to consist of numerous small units of chromatin called genes which are arranged in a single row similar to an orderly row of blocks or of popped corn, each of which differs from the others in some way. This difference may be one of chemical arrangement in the protein molecule. Since these units, thought to be the genes, have been seen in the salivary gland cells of the common fruit fly and, less clearly, in certain plant cells, they are believed to exist, and further evidence substantiates the theory that each becomes a determiner of, or a carrier for, a particular characteristic. In other cases a number of genes together

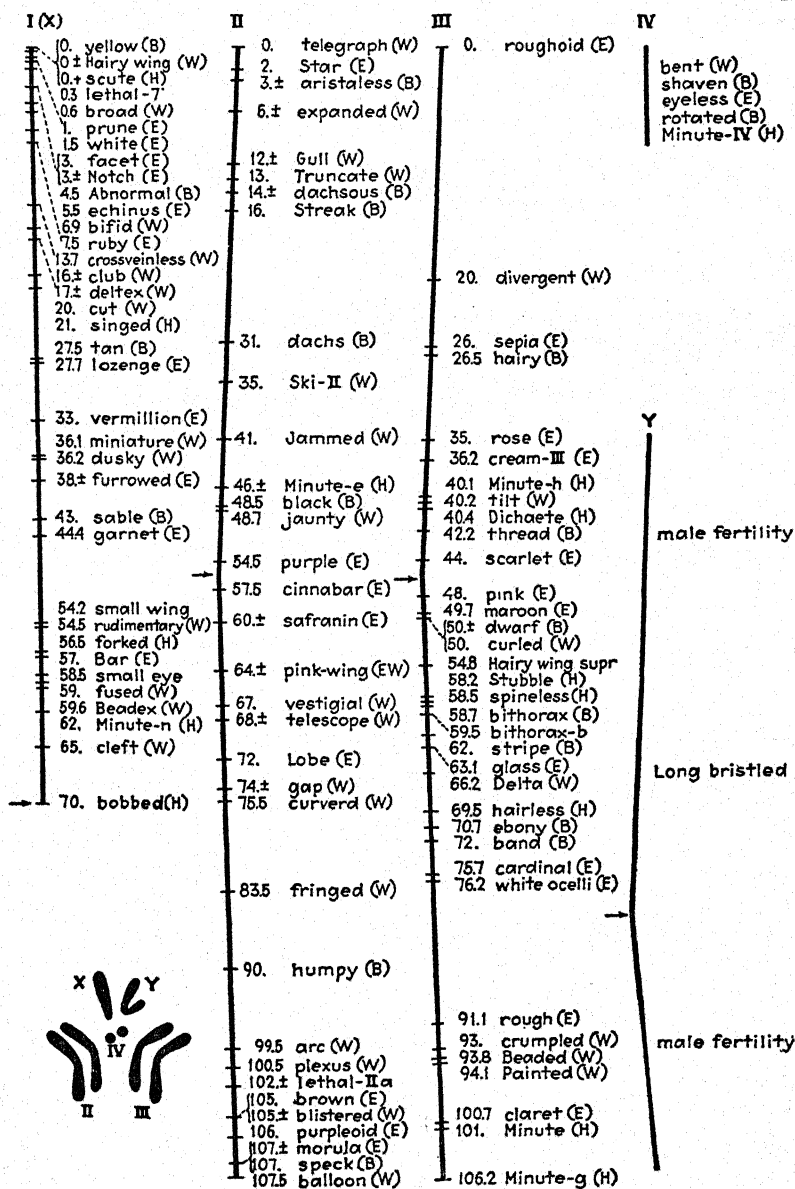


FIG. 7. Linkage map for *Drosophila melanogaster*, showing relative positions of many of the known genes in the chromosomes as determined genetically. The letters in parentheses indicate the portion of the fly in which the characters appear: B, body; E, eye; H, hairs; W, wings. (From Sharp's Introduction to Cytology, 3rd edition adapted from Morgan, Sturtevant, and Bridges (1925) and Stern (1929), McGraw-Hill Book Co., 1934.)

are thought to be responsible for a single characteristic. The number of genes to a characteristic chromosome is variable, but usually there are more than one hundred and in some cases perhaps many hundreds. The exact location of genes in the chromosomes has been attempted as is shown in the study of the fruit fly (Fig. 7). It should be borne in mind that most of the evidence for genes and all the evidence that they carry hereditary characteristics is experimental and not something seen with a microscope. This will be described further under the title of "the hybridizing of plants."

Cell division must be understood to appreciate plant growth and to deal with plant breeding. Cells divide only where growth is taking place. These growing places are the meristematic regions found at the tips of all roots and all stems, in the cambium region of dicotyledonous plants and at the base of the internodes of monocotyledonous plants. A few specialized regions of division might be added such as in very young growing leaves, in the developing flower parts, and in fruits and seeds. It should be remembered that every organism begins as a single fertilized egg cell and by the process of cell division, growth and specialization a single cell becomes a plant or animal with many millions of cells. Reduction division, in which the number of chromosomes is reduced in the formation of sex cells, is described in Chapter 18.

The diagrams of Figure 6 show certain stages of division in a continuous process which can be better shown with motion pictures. It should be noted in numbers 2 and 3 that in the resting cell the chromatin of the nucleus forms a thread. This thread splits longitudinally in number 4, and in number 5 is broken to form the numerous chromosomes each of which contains a portion of every gene. These newly formed chromosomes grow to normal size and arrange themselves across the equator or center of the cell as shown in number 5 and then pull apart and begin to move toward

the opposite ends of the cell in numbers 6 and 7, so that each end will have exactly duplicate sets of chromosomes, like the cell from which they came. A wall forms in numbers 8 and 9, dividing the cytoplasm to make two new cells. The chromatin returns to the resting condition in number 10. This phenomenon is repeated hundreds and hundreds of times in the development of every plant, in fact it takes place during all the growing periods throughout the life of the plant.

REFERENCE

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Chapter Five

ROOTS

The root will be used as a beginning point for a detailed study of the structure of the various parts of the plant. This will be followed in the two succeeding chapters by root functions as related to the soil. Roots are usually the least studied of any part of the plant because they are inconspicuous and difficult to free from the soil. When their important functions are appreciated it becomes clear that they are of the utmost importance for the best growth of the plant.

The root systems of plants are divided into primary, secondary, and adventitious roots. The primary root of a plant develops directly from the seed when it germinates. The roots coming from the primary root and all their branches are known as secondary roots (Figs. 4 and 5). All other roots, whether they arise from stems or leaves, are adventitious roots. All secondary roots originate within the root while it is young, near the xylem region, and push through the outer tissues into the soil.

Root systems are divided into two groups according to the nature of their growth. A tap root system results from the continuous and vigorous growth of the primary root, such as in carrots, alfalfa, and many of the trees. The garden carrot has a tap root, the top of which is modified for food storage but a thin part of it may penetrate the soil more than seven feet, according to Weaver and Bruner in their book on "Root Development of Vegetable Crops." They found the secondary roots extending in every direction from the tap root to a distance of two and a half feet or more.

A longitudinal view of a carrot may be used to describe some of the structures common to young roots. The central

part, usually more than one-third the total diameter of the root, is xylem or stele through which conduction of water and other substances takes place. The cambium is at the outer edge of the xylem while the more tender outer part consists mostly of cortex with the pericycle and phloem, a narrow band, next to the cambium. The secondary roots can be seen as light-colored threads passing through the cortex region from their origin in the xylem, where they grow when the root is very small. While they push through some tissue, much of the cortex grows around the secondary roots after they have grown some distance into the soil. Seeds of plants with tap roots are usually started in permanent beds because tap roots broken in transplanting branch and may weaken the plant. It would be an important problem to determine the effect in several types of soil of transplanting on a wide variety of plants with a pronounced tap root.

In sharp contrast to the tap root, the fibrous root system results from a slow-growing tap root and fast-growing secondary roots, such as in grasses (oats, Fig. 4), or, as in the adventitious roots, from a more or less even rate of root growth, such as is common from the nodes of certain grasses. This type of root system is usually more shallow than a tap-root system and may suffer sooner from drought. Some of the horizontal roots of both systems may be so near the surface that they are easily destroyed in cultivation. These horizontal roots may be in dry soil where frequently no water is available. However, since the soil is always well aerated near the surface, these horizontal roots are very important to the plant in its absorption when the deeper soil is so wet that its oxygen content is seriously reduced.

The root system of a maturing lima bean plant shown in Figure 8 represents a weak tap-root system, with extensive branching near the surface, and illustrates the type of system which suffers from drought because many of the roots are in the upper four inches of soil. This shoot was nineteen inches

high and the leaf spread was thirty inches in diameter in comparison with the root depth of five feet and root spread of more than six feet. In such a plant the absorbing area of the root system is considerably greater than the surface of the shoot, through which the water is lost.

Adventitious roots arise at any unusual place such as on a vine or tomato stem that comes in contact with the soil.

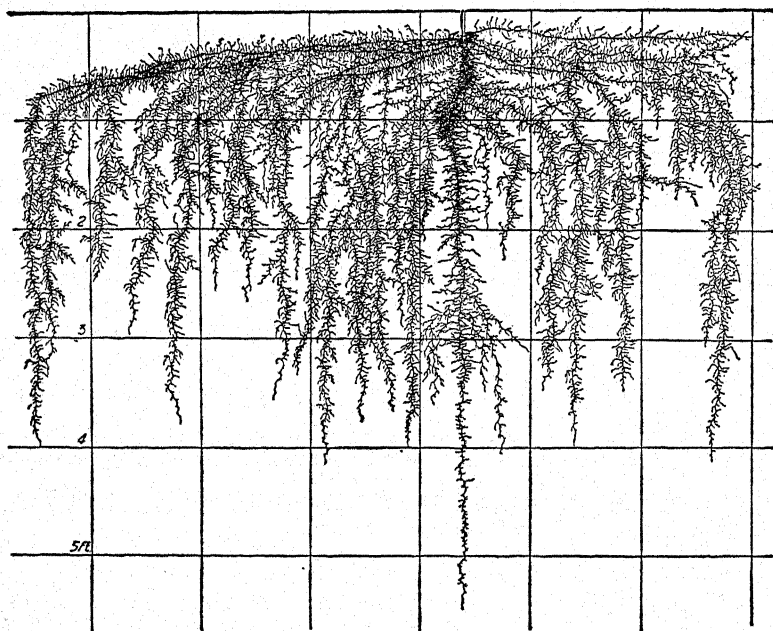


FIG. 8. The great extent of a maturing lima bean plant is shown. Two hundred cubic feet of soil were ramified by the roots of a single plant. (From Weaver and Bruner's *Root Development of Vegetable Crops*, McGraw-Hill Book Co., 1927.)

Cuttings depend entirely on the development of adventitious roots. In transplanting, should a large part of the normal absorbing root system be destroyed adventitious roots will develop. It is doubtful if adventitious roots are as successful for plants as the normal ones, when distribution in the soil and the union with the plant is considered in relation to the growth of the mature plant. It must be noted, however, that this question is not settled for all plants, and many

plants are improved by the increased number of adventitious roots caused by transplanting. Probably the whole problem of cuttings as compared with other means of propagation rests on this question. It is also possible that with the newer methods of chemically stimulating the rooting of cuttings they will be more successful. A number of simple experiments will suggest themselves to those interested.

The structure of a root is complicated to fit it for the many functions of the root system. The chief functions are absorption, conduction, storage, and anchorage. The younger, more active and interesting parts of roots can be seen to the best advantage if they are grown in a very loose, open soil, from which, if they are lifted gently, the root cap and growing region, about one-fourth inch long, will protrude from a mass of soil held around the older root by a mat of root hairs. Or seeds may be germinated on moist paper where the individual root hairs may be seen from the smallest to their normally mature size, as shown in the enlarged view of Figure 11.

Absorption is so important to the growth of plants that the following chapter has been devoted to its more detailed study, but it should be noted that only the younger portions of roots, those without a cork layer, are permeable. Most of the water and mineral salts enter the roots through the root hairs shown much enlarged in Figures 9, 10, and 11. They are extensions of certain of the outer cells of the root. Since the root must supply these materials for the entire plant, it is not surprising to find cells adapted to conduction at the regions of absorption, shown best in Figure 10 as tubes, collectively called xylem in the cross section of a young root in Figure 9. The phloem cells, through which foods reach the roots from the leaves, are less prominently developed here. In older roots, the xylem is a large part of the root. In perennial plants the roots continue to add to the xylem, phloem, and cork areas, but the cortex may decay and disappear.

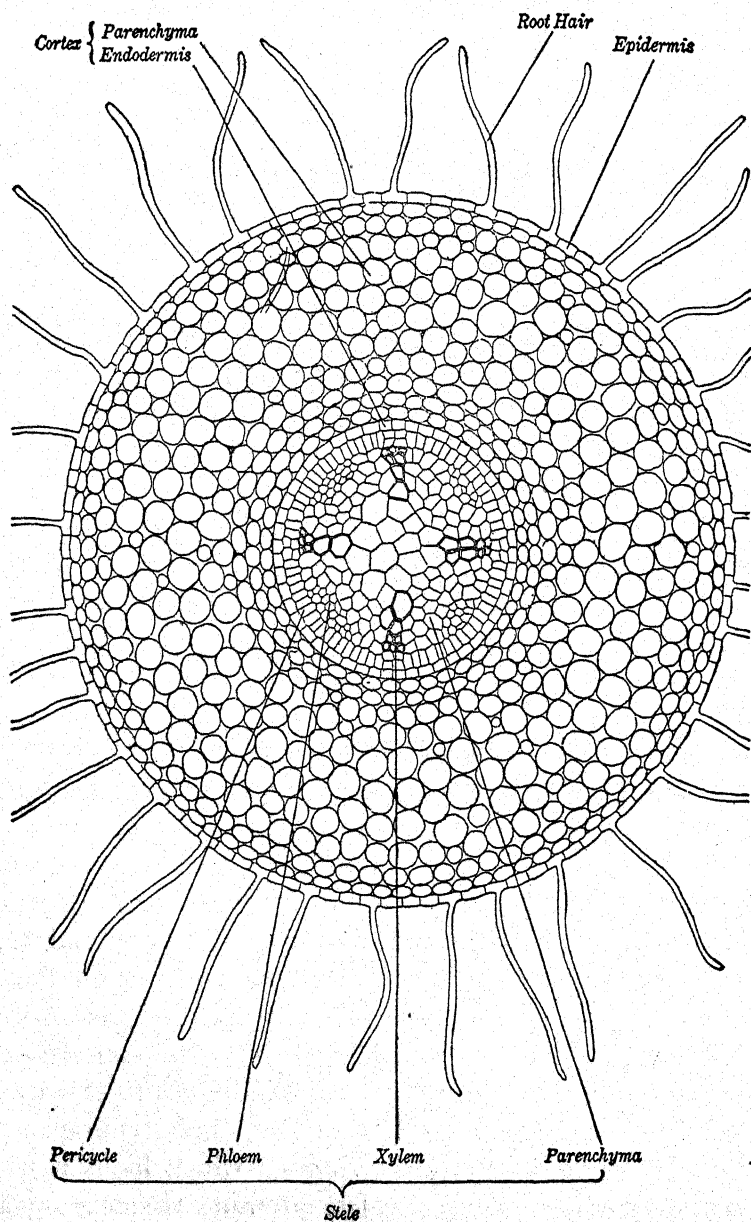


FIG. 9. Cross section of a young root. Root hairs and the small amount of xylem and phloem are characteristic. (From Smith *et al.*, A Textbook of General Botany. By permission of The Macmillan Co., publishers, 1935.)

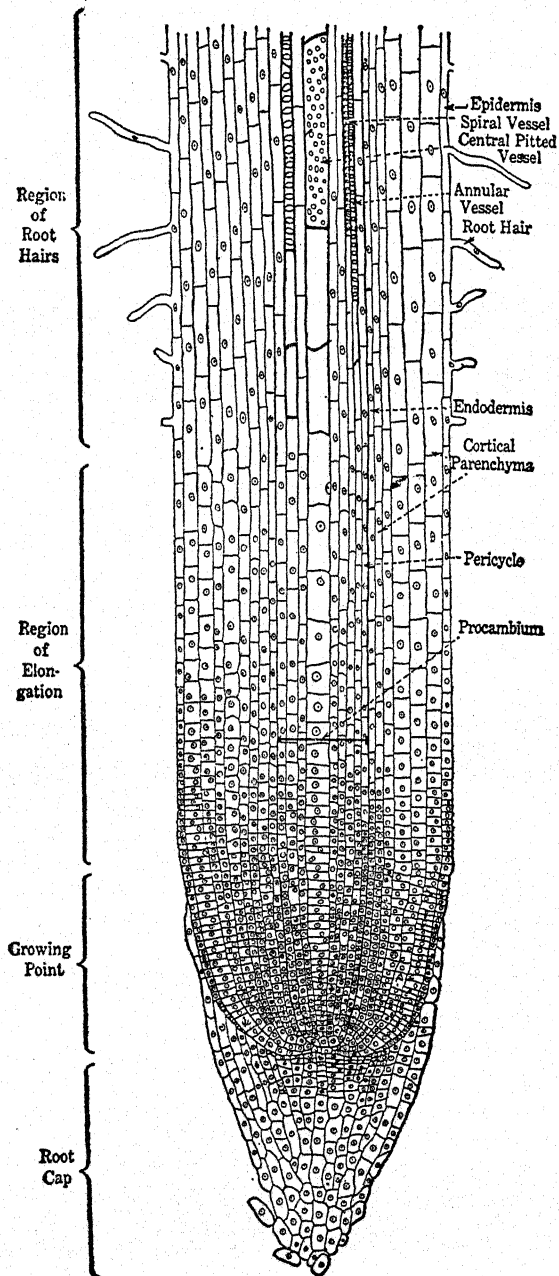


FIG. 10. Longitudinal section of the root of barley (*Hordeum sativum*). (Reprinted by permission from Holman and Robbins' *Elements of Botany*, John Wiley and Sons, 1938.)

The growth in length of the root and its pushing through the soil has been of interest to many. Darwin tried to figure the energy necessary for a root to enter the soil and in his investigations did find that it grows with a rotating motion, which enables it to go through the softer areas or

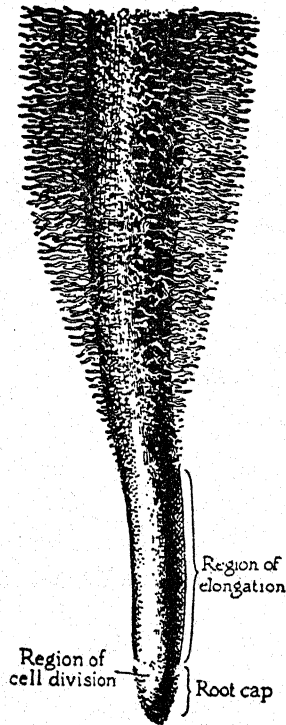


FIG. 11. Enlarged view of the end of a root, showing root cap, growing region and root hairs. (From Transeau, Sampson and Tiffany, Textbook of Botany, Harper and Bros., 1940.)

openings in the soil. The force, more recently, has been found to be derived from osmotic pressure.

The growth in length, shown in the section of Figure 10, takes place within a quarter of an inch, just back of a group of tough cells called the root cap, often visible with the eye. The growth area may be divided into two regions; the growing point where the cells divide, which is about one-thirty-

second of an inch long and is found just back of and inside of the root cap, but merging into the second, where most growth in length occurs. Fully grown cells may reach fifty or more times their length at the time of cell division. When fully developed they begin to change their character in the region of the root hairs to become the various tissues of the mature root. These areas of development may be located in a general way on a young root similar to the one in Figure 10, when the root cap and dividing areas are slightly darker. The root hairs appear as a white covering.

Food storage is an important function of the roots of biennials and perennials. The abundance of plant food stored may be seen by covering a cross section of a root with a solution of iodine¹ for a few minutes, washing, and observing the blue-stained starch in the tissues of the root. This is used during the rapid spring growth of root, stem, and leaves. For this reason the plants which have favorable conditions during the summer will have stored more food and therefore will make a better growth the following spring. Furthermore, most plants have rapid root growth before the buds open in the spring, for which they depend entirely on the stored food, therefore, it is likely that the successful growing of plants depends largely on the storage of food. Late summer growth takes stored food which should be reserved for spring and in addition the growth is so tender that it often winter-kills. This can be largely regulated with fertilizers as explained in Chapter 22. A perennial will usually have more food stored in the root and the stem than will be used for the spring growth, as may have been noted when a thrifty plant has had enough reserve stored food to grow a new set of leaves if the first set has been destroyed by frost or insects in the early spring before storage had taken place.

¹ A solution of iodine for this purpose may be made by dissolving potassium iodide in water at the rate of one-half ounce per quart of water and adding one-tenth of an ounce of iodine crystals.

Anchorage may be incidental to the structure for conduction of the root but its importance cannot be questioned, since it is necessary that a shoot be in a position to get an abundance of air and light. Recent work in plant breeding has stressed the character of a root system that provides good anchorage, notably in the breeding of corn.

Root hairs are tubular projections of the epidermal or outer layer of cells of the young root (Figs. 9, 10, 11). Root hairs are frequently less than a sixteenth of an inch long, but there may be in some cases a quarter of a million per square inch of root surface, which will increase the absorbing surface ten times or more. The figures show the normal position of root hairs, as they begin just back of the elongating region and extend some distance along the root. When the older root develops the corky layer the root hairs die. From the above it is clear that the absorbing region of a root system moves farther and farther from the plant, or in other words into new absorbing areas.

With favorable conditions the root system grows surprisingly large; in fact, studies have shown the root spread to be much greater than the shoot spread, resulting, even in larger trees, in a relation similar to the one described for the lima bean. Studies of root growth all indicate that their spread is more than twice as great as the ordinary planting distances, resulting in severe competition in the soil in their growth and for the absorption of water and salts. This is true for most of our garden plants unless we supply excessive amounts of available fertilizers, and apply frequently an optimum amount of water, both of which reduce the growth of root systems.

Perennial grass plants grown with unlimited space have been found to grow as much as a total length of one hundred fifty miles of roots each year, but never exceeding a total root length greater than about three hundred miles, since after reaching that length the older portions die at about the same

rate that new growth occurs. Lawn grasses grow in severe competition with each other and also have the leaf surface reduced by frequent cutting, both of which restrict the growth of the root systems, but they doubtless grow new root areas while others die in a similar way. In the same way parts of the roots of trees die as other roots grow. These decaying roots are very beneficial to soils by adding humus and leaving pores for the exchange of air and the entrance of water, preventing run-off except in unusually heavy rainfall.

Mycorrhiza is a symbiotic fungus growth on the young roots of many plants, especially trees, which prevents the growth of root hairs, but does their work in the absorption of water and salts from the soil for the plant and in return gets mycorrhiza food from the plant on which it grows. It is now considered to be so beneficial to the growth of forest trees that extensive experiments in the inoculation of plantings in new areas are in progress. The fungus covers the young roots with a dense compact mantle of fine hyphae like those of the common bread mold but much more extensive than the ordinary growth of root hairs, and may have functions in addition to those ordinarily attributed to the root hairs. In the woods, especially in the spring or fall, one may see many toadstools, some of which are the spore-bearing structures of the mycorrhiza on the roots of the nearby trees.

Chapter 21 deals with the problems that the gardener must consider to improve the conditions that favor root growth. It has been shown that roots grow longer and branch more with a low or medium soil moisture, than with a high soil moisture; this may be associated with aeration. Since roots do not penetrate a hard compact soil so freely as a looser one, deep cultivation, even trenching, before planting will encourage the development of the root system in a larger volume of soil. Roots branch more in a soil with a favorable amount of mineral salts. Organic matter in-

creases root growth, due to the products of its decomposition, and the aeration of the soil.

The importance of a good root system cannot be questioned. The root system must extend through a large volume of soil in order to get an abundance of mineral salts and to get enough water even under conditions of drought. The root system stores food for spring growth of the shoot; therefore, a good top can grow only on a good root. But the roots cannot be seen, neither can they be judged by the tops under all conditions, since high nitrogen may cause the tops to look vigorous and depress the root growth. The gardener must study his plants from year to year in order to learn the best methods to be used in growing them, therefore, the roots require thoughtful consideration, because the tops will surely disgrace the grower who neglects the roots.

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Chapter Six

ABSORPTION OF WATER AND MINERAL SALTS

Animals, including man, depend on food made entirely by plants, and made, as all the foods found on the earth are, from simple materials, which animals cannot utilize as food. From water and carbon dioxide plants make the world's supply of starch as is explained in Chapter 12, and the mineral salts they use in the manufacture of protein. Plants can get these materials only in the smallest units in which they exist, called molecules or in at least some cases, atoms or ions. A molecule is so small we can imagine nothing small enough to compare with it. Bacteria, visible only with very good microscopes, are very large in comparison. It would be necessary to have at least a billion water molecules in a group to be visible to the naked eye. In addition to being very small, every molecule is in motion independent of the motion of every other molecule. Food material for plants must always be in that condition when it is absorbed by a plant. Solids, as salts, or gases, as carbon dioxide, must be in the form of molecules dissolved in water when they enter a cell of a plant.

Diffusion is the term applied to this movement of molecules and ions when they move from regions of higher concentration toward regions of lower concentration. Each unit moves independently of all other units which may surround it, as for example, sugar molecules may move from a lump of sugar into water while the water molecules move among the sugar molecules. This movement results in a uniform distribution of the sugar and water molecules. Other common illustrations are: the diffusion of ether molecules from the liquid condition as it evaporates among the molecules of

air, or the diffusion of salt through meat. Diffusion from the soil into the plant will be discussed later.

Osmosis is diffusion of molecules through a membrane. This is of great importance to an understanding of the plant's processes of absorption and excretion. The cell membrane of protoplasm acts as the membrane which is permeable to water, salts, and some organic molecules, but it is not permeable to sugars and proteins, or at least only very slightly. A membrane of a root hair filled with cell sap, in contact with the soil water, is a good example.

The cell sap consists of a sugar, soluble proteins, mineral salts, and plant acids in a water solution. Since so many molecules are dissolved in the water, the solution is concentrated, or the amount of water is less than in a solution with fewer dissolved molecules. Various cells of the plant differ in the concentration of their cell sap. It is usually lowest in the water-conducting cells. It may vary from less than 1 per cent to 20 per cent but is usually close to the lower figure. The concentration becomes greater in dry soil and less in more moist soil.

The water in the soil, or the soil solution, has mineral salts and products of decay, but seldom sugar, and the total concentration must always be less than the concentration of the cell sap of the root hair. When this is true, the water diffuses from more water in the soil solution toward less water into the root hair. If excessive amounts of salts, as fertilizers, are applied to the soil, it may increase the concentration of the soil solution above that of the cell, causing the water to go from the root hair to the soil. This would cause the plant to wilt and die. One method of killing weeds is to apply salt to the soil in sufficient quantity to prevent the diffusion of water into the root hairs. In large areas of soil there is little danger of killing plants with fertilizing salts, but in flower pots only small amounts may be used.

The cellulose walls of the cells (Fig. 6, A) are in the form of very small needle-like crystals separated by exceedingly

thin films of water. It is important to note that these films of water connect the water of the soil to the water of the protoplasm and cell sap of the cell. The root hairs are between and around the soil particles and make the water contact between the plant and the soil. If the connection of the root hairs and the soil is broken, as happens in transplanting, the plant cannot get water by diffusion until new contacts are made. It is for this reason that the plant must be guarded against excessive transpiration after transplanting.

Mineral salts must be in a water solution in order to be diffusive. They follow the same law of diffusion as explained for water molecules, that is, they tend to go from where there are more of a certain kind of molecules or ions to where there are fewer of them. Calcium ions may serve to illustrate in general the absorption of mineral ions. The calcium must first be in solution in the soil water. Oyster shells or lime applied to the soil must form a solution to be valuable. As the plant's content of calcium is used, perhaps to form a part of the cell wall or insoluble crystals of calcium oxalate, the concentration of calcium in the water in the cells becomes lower than the concentration in the soil solution around the root hairs. When calcium is more concentrated in the water outside the cell than in the cell it will diffuse into the cell. Since there is a constant use of calcium by a growing cell, it follows that it will be absorbed, that is, it will constantly diffuse into the cell.

Poisonous ions, if they are present in the soil in solution, may diffuse into the plant in the same way that useful ions enter. It has been suggested that the residue of continuously spraying with copper and arsenic sprays might become dangerous to the plants and the plants might become poisonous as food. Since these ions would be continuously removed by plant growth and by leaching from the soil, it is hardly possible that such a danger exists. Selenium is an element found in certain soils and is therefore absorbed by plants. It appears to be more toxic to animals than to plants, and

for that reason plants grown on such soil have been found to be poisonous to animals including man. Such cases are very rare.

Turgor pressure is the force of the cell contents against the cell wall. This pressure is produced by the osmotic action of the water through the cytoplasmic membranes. The phenomenon of turgor pressure is important in many activities of the plant. It, as has already been explained, is the force which pushes the root through the soil (see page 36). It is the pressure which causes the stretching of the cell walls in growth. It keeps the leaf and stem cells from wilting. It causes the seed and the pollen grain to germinate. Turgor pressure might be said to be a force in every living cell.

Turgor pressure acts as a balance on the absorption of water by a plant. Since osmosis is the force by which the water tends to enter the cell, turgor pressure within the cell tends to balance or prevent the entrance of water. When a plant is wilted, it has no turgor pressure, hence there is no force to reduce the entrance of water. When a plant is turgid or has a high turgor pressure, more force must be overcome when water enters. Turgor pressure may vary from zero to several atmospheres, depending on the water and the soluble matter in the cells of the plant and in the soil.

The turgor pressure of the cells varies through the day. The amount of water tends to decrease because transpiration is faster than absorption. The amount of sugar tends to increase in some plants during the day; in other plants the sugar of photosynthesis is changed to starch with no effect on the cell-sap solution. As the water of a cell decreases and/or the soluble substances increase, the turgor pressure of the cell increases.

A few mineral salts are being found which do not obey the old commonly accepted laws of diffusion in their absorption by plants. Potassium, for example, is absorbed in much

larger amounts than can be explained by diffusion. Potassium goes from a more dilute soil solution to a cell with a higher concentration of the ion. It appears to be absorbed several times more rapidly when the roots have readily oxidizable food material and plenty of oxygen, and may be a case of actual plant energy used in absorption. If this is true, and the evidence is most convincing, salt absorption is the result of work by the plant and can be controlled by enzyme and hormone regulation. This research is in progress and may suggest methods of stimulating these growth regulators to speed up the development of the plant. Other elements appear to be absorbed with difficulty and a wide difference in their concentration is always found. In some cases the cell sap has a very low concentration of the ion. This is spoken of as selective absorption. Much research work has been done on this problem, but we have many unanswered questions. The following table shows one of the cases of unequal diffusion of elements by a pondweed:

*Analysis of the sap of Nitella and of the pond water in which it was growing,
by Hoagland and Davis*

Ion	Concentration in sap	Concentration in pond water
Ca	13.0	1.3
Mg	10.8	3.0
Na	49.9	1.2
K	49.3	0.51

In the case above all the elements are more concentrated in the cell sap than in the pond water, but note that the Mg is three and one half times as concentrated, while the K is almost a hundred times as concentrated. These are not uncommon results.

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Chapter Seven

THE SOIL

The soil, that complex substance forming the outer layer of the earth's surface, is a great reservoir of water and mineral salts essential for plant growth. Many different kinds of soils will furnish the necessary materials for plants, but a good soil has a proper balance of the following five constituents: mineral particles, water, air, organic matter, and living organisms.

The basic material of most soils is the mineral particles of varying size formed by the decomposition of rock. Sandy soil has a high proportion of coarse particles; silt soil has a base of exceedingly fine particles. In the eastern United States most soils are mixtures of various sizes of particles. The size of the soil particles is important because the surfaces hold the water and mineral salts which the root hairs absorb. A single cubic foot of fine garden soil may have more than ten thousand square feet of soil particle surface, while a sandy soil has only 10 per cent as much. Since this difference in soil surface results in a proportional difference in the *water-holding capacity* of soil, sandy soils require more frequent watering than fine soils for good plant growth.

The kind of rock from which soil has been formed is very important because some soil particles are continuously dissolving to furnish the mineral salts in solution for the plants. A soil formed by a combination of rocks is more productive than one from shale or slate alone. Some of the best soils are largely from a limestone origin. However, the degree of weathering usually is more important than the parent rock from which it is formed.

Plants absorb their minerals from the capillary water solutions. A rich soil has a greater supply of soluble material than a poor soil. Thus many soils can be improved by increasing their acidity so that the rock particles will be dissolved more rapidly, and by checking excessive drainage which loses fertility to the underground water.

The amount of soluble matter may vary from time to time even though in general the insoluble portions continue to become soluble. It may be reduced by greater absorption at times of rapid plant growth, and during rainy periods when some of the soluble material may be carried from the soil in the underground drainage water. A soil with a greater water-holding capacity should be better able to supply plants with mineral salts. The soluble and insoluble composition of fertilizer, as shown by analysis, should be studied in any effort to improve soil. It should be kept in mind that while the insoluble is unavailable to the plants, it slowly becomes soluble and available. Bonemeal and other organic materials are among our best and safest fertilizers because they become slowly available.

The growth and development of all organisms is a response to environment, which for plants is air and soil. Man has been able by plant breeding (discussed in Chapters 18 and 19) to make plants that are better adapted to certain environments, and although he has little power to regulate the temperature, the sunlight, and the rain, he can use the basic mineral soil available to him and can alter the properties of the soil complex most markedly in many ways. Soil science has made it possible to make a soil suitable for practically any plant. The first steps of improvement might include the increase or decrease of the organic matter, the number and size of air spaces, the numbers of living organisms, the relative acidity, and of the temperature and water-holding capacity of the soil. Soil improvement requires a careful study of the soil and the response of the plants to the

soil, followed by careful experiments with various methods used to build better soils. Constructive work may be done each year, when a well-managed soil should continue to get more productive.

By irrigation and sprinkling to improve the water content of soil the growth of plants is probably improved most because growth is restricted more by unfavorable soil water content than by any other single factor. Soil water is often divided into three types: capillary, gravitational, and hygroscopic.

Capillary water is that water which is held to the soil particles by cohesion or molecular attraction. The excess of water that passes through the soil after a long rainy period is called gravitational water because the pull of gravity overcomes the force with which the water is held to the soil. The capillary water is in thin films covering every soil particle to a varying thickness depending on the moisture content of the soil. A sandy soil may hold as much as 20 per cent of its weight as capillary water which would be available to growing plants, but a fine soil with a high colloidal and humus content may have a capacity five times as great as the sand. As the plants take water from the soil, or as it evaporates, the films become thinner. The force with which the water adheres to the soil is inversely proportional to the thickness of the film, which may become so thin that the plant absorbs it more slowly than it loses water by transpiration; therefore, it may wilt during the day but recover at night when the plant loses water very slowly. Finally, the reduction of water in the soil increases the force with which it adheres to the soil particles, until the force holding it to the soil is equal to the force with which it enters the plant and absorption ceases. To go back to the theory of diffusion, the concentration of the cell sap is not great enough to cause the water to diffuse from the soil particles into the root hair. This balance of forces is reached while the films are thick enough to

give up a little water to a dry atmosphere by evaporation. When water no longer evaporates from a soil, it is said to be air dry, and the water remaining is called hygroscopic water, most of which can be removed by heating the soil.

The following simple experiment tests the water-holding powers of soil. Pulverize a quantity of soil and dry it for several days in the hot summer sunshine or in an oven at about boiling temperature for a day. Gently tamp two pounds of the dried soil in a tin can, of about one quart capacity, with a few perforations in the bottom. Slowly add water, an ounce at a time, until it is well soaked and the excess water drips from the can. The percentage of water held by the dried soil is known as the "*water-holding capacity*" of the soil. A good soil should hold 50 to 100 per cent of its weight in water. The water that was not held by the capillary forces of the soil, but passed through the perforations, was the gravitational water.

The movement of the water in the soil depends on the fact that it is in continuous films from soil particle to soil particle and is held to the soil particles with a force proportional to the thickness of the film. If water enters a root hair, the film at that point becomes thinner and the pulling force of the soil increases, which causes the water to move in that direction. This is the movement of capillary water and it is similar to capillary movement in a finely drawn glass tube or even the slight curve of the water at the surface on the sides of the tumbler at the dinner table. The reverse holds true; when water is added to the soil, the films become thicker and the water moves by capillarity to where they are thinner. This movement is very slow as can be seen by digging into the soil after a rain. Since some force is necessary to cause the water to move through the soil there is a tendency for it to accumulate near the surface after a rain, by increasing the thickness of the films, instead of becoming equally distributed on all the soil particles even at greater

depths. The "field capacity" is a term used to express the amount of water held by a soil to a given depth. Only additional water will pass to the deeper soil, and will increase the depth to which the field capacity has been reached. This will be considered later under the heading of artificial watering.

The mineral salts in solution in the capillary water will move with the water, but they also move by diffusion. If a root hair is absorbing a particular ion (the smallest unit of an absorbed substance, as an ion of potassium) faster than it is absorbing the water in which it is in solution, the concentration of the ion will be decreased which will cause that kind of ion to move by diffusion toward the root hair at a greater speed than the solution. In other words, ions and water molecules enter the root hairs as individuals by diffusion, and they may move that way in the water films around the soil particles instead of moving as a group of mixed molecules, which make a solution such as a drop of a sugar solution.

The water-supplying power of any soil refers to the amount and the rate at which the plant can absorb water from the soil. Since the water moves by capillarity in the soil, it is clear that a plant can get from the soil the water immediately around the root hairs and the water that will move to the root hairs. A soil of finer texture, other conditions being the same, will hold more water, in proportion to the increase of particle surface in contact with a root hair, than a coarser soil. It is evident for this reason that a fine soil will normally supply more water to plants than a sandy soil and that plants will wilt sooner in a sandy than in a fine soil.

The air of the soil is necessary to supply oxygen to roots and to the organisms causing decay. Protoplasm must have oxygen to grow or in fact to live. A loose porous soil with a low water content will contain a large quantity of air. The oxygen can diffuse into this air as it becomes depleted of oxygen by the roots. However, a soil with too much water

will be deficient in air and growth will be retarded. This need of oxygen can easily be tested by trying to germinate seeds in boiled water which has cooled and has a layer of oil over it to keep the oxygen out and in other water that has been vigorously stirred to oxygenate it. Roots will seldom enter soil, because of slow growth, where oxygen is limited by lack of air spaces due to excess water or to the fact that the soil particles are packed.

The organic matter of any soil can be increased by frequent applications of manure or other vegetable matter. It has such a profound influence on the soil that it should be given a great deal of consideration. Plant growth can be improved more by building up the organic matter of the soil through yearly applications than by any other method with the exception of the use of water in cases of drought. Organic matter not only gives a darker color to the soil which will cause it to absorb more heat and make it warmer in the spring, but it increases the water-holding capacity, since it may hold several times its weight in water. Organic matter decays slowly, forming acids which favor the dissolving of rock particles, and the decayed matter furnishes the food material for the growing plants. Recently it has been ascribed greater importance as food for the organisms that cause its decomposition. For example the bacteria that live in the soil and fix nitrogen must have large quantities of organic matter from which to get their food in order to reproduce, grow, and fix the maximum amount of nitrogen. Organic matter may some day be considered of most importance because of the soil organisms it supports.

The living organisms of the soil, most of which are beneficial, are so numerous that only a special student studying small amounts of soil with the thoroughness of the bacteriologist can appreciate their importance. Many of these fungi and bacteria are important in bringing about the decay of the organic matter of the soil, others as described in

Chapter 23 add much of the nitrogen to the soil. Larger organisms as the worms of various kinds improve the soil by aeration and water absorption through their burrows. Plants will grow in a soil free of these living organisms but the soil will not remain fertile.

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Chapter Eight

STEMS AND BUDS

The stem is the structure, usually above the ground, which bears the leaves. It develops from the plumule part of the seed (Plate I). The tomato seedling at the left shows only a bud-like plumule which develops into the shoot in the other two stages. There are a few underground stems such as the white potato tuber and the rhizomes of quackgrass and ferns.

The nodes of stems are usually swollen areas from which the leaves grow. The above plate shows a node with its compound leaf, and the buds which appear just above the leaves develop into branches (Plate II). The two growing buds may be seen just above the lower compound leaves; the upper one is a sizeable branch. The length of internode, which is the distance between two nodes, depends largely on the growth conditions at the time of development. If they are too long the plant probably lacks light, has too much water, or nitrogen. The cabbage plants shown in Plate III were grown with light and minerals limited to starve them. They show many leaf scars very close together because the internodes are short.

Stems of garden plants are of two kinds, first monocotyledonous, such as corn and lily, which usually grow in length chiefly at the base of the internodes, branch sparingly, increase in diameter only a little, and have the woody fibers scattered more or less evenly through the pith. The second are dicotyledonous plants, such as tomato and all broad-leaved trees, which differ in all these particulars. They grow in length just back of the terminal bud, branch more freely, increase in diameter by adding cells at the cambium layer,

and have the woody region in a more or less heavy cylinder between the pith and the bark. The buds are usually more conspicuous on this type of stem than on the monocotyledonous stems.

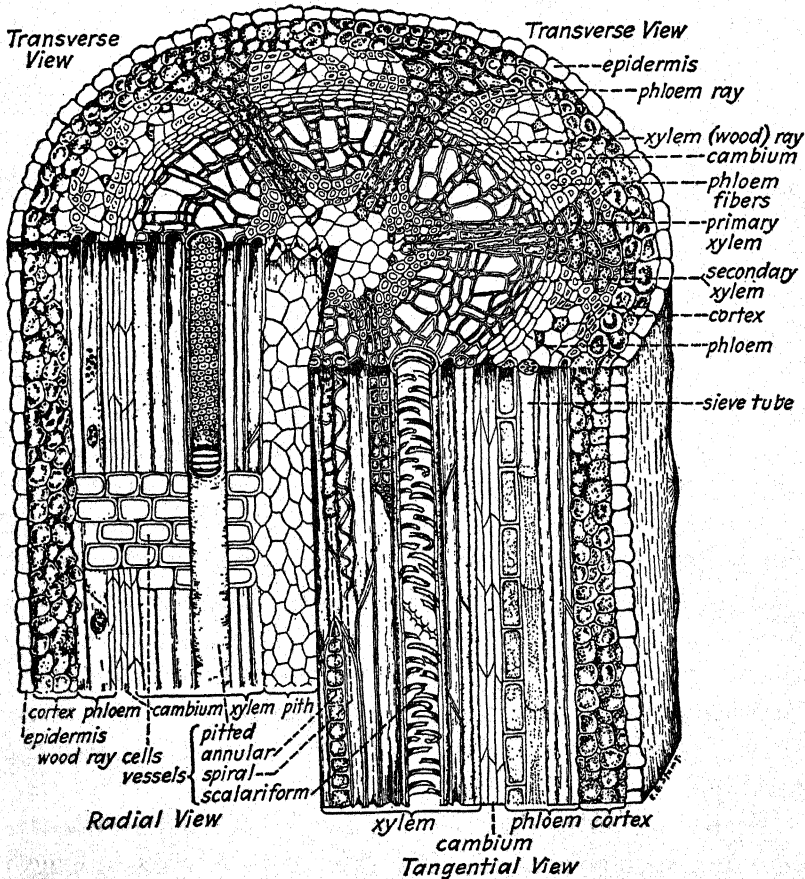


FIG. 12. Semidiagrammatic representation of a one-year-old stem of tulip-tree, in transverse, radial, and tangential views to show the relative size and shape of the many kinds of cells. (From Hill, Overholts and Popp's Botany, McGraw-Hill Book Co., 1936.)

The main tissues of the stem correspond with those of like functions in the roots. The central region is the pith, usually absent in roots. In young, and in herbaceous stems



PLATE III. Cabbage plants grown 26 months with low light and in small pots. The starved plants have lost many leaves as shown by the nodes. (1/3 natural size.)



PLATE IV. Detail of whip graft. (1) stock, (2) stock and scion, and (3) graft completed and tied.

which grow for only one year, food is stored in the pith. The wood or xylem tissue carries the water through the stem to the leaves and forms the chief part of a woody stem but only a small part of an annual plant, or even in a one-year-old woody stem, as illustrated (Fig. 12) by the main tissues in the tangential view of the first year's growth of the stem much enlarged to show the cells in detail. The xylem cells vary in shape and size both in longitudinal and cross section. Some people believe that all the mineral salts go up through the xylem, but others believe that a part of it goes through the phloem. In trees large quantities of food may be stored in the xylem.

The cambium is a layer of cells around the xylem. It divides repeatedly during the life of the plant to add new xylem cells on the inside and new phloem on the outside, increasing in this way the diameter of the stem. The bark consists of the several types of cells found outside the cambium. The phloem which is next to the cambium carries food material through its sieve cells from the leaves to other parts of the plant. The cambium cells break when the bark is removed from a woody stem during active growth. Outside of the phloem a stem usually has a cortex made up of thin-walled cells in which food is stored. Older stems have a band of varying thickness of corky cells on the outside to prevent excessive loss of moisture. Younger stems have a single layer of epidermal cells with cutin on the outside to retard the loss of moisture. Since the outer layer of bark sloughs off in pieces from older trees the cork becomes the outside layer.

For a few weeks in the spring, from the time the buds begin to swell, the stems of most perennial plants grow in length after which the cells thicken and become permanent tissues. The leafy stems of twig C (Fig. 13) grew in the spring and have ceased to grow in length. Other stems, such as the tomato, geranium, petunia, and most of the other her-

baceous plants, continue to elongate during most of their period of life.

Growth in thickness of woody plants is most rapid also in the spring but it continues all summer at a slower and slower rate. The difference in the growth rate in late summer and the following spring can be seen by the much larger spring cells, which make the yearly rings so conspicuous in cross sections of wood. They are equally clear as long streaks in oak flooring and in much of the wood of our furniture. The limited summer growth enables the plants to store food for the early growth of the following year.

Buds appear on new wood at the axils of the leaves about the time the leaves appear. Buds which are clearly evident on the above twig C will continue to grow larger through the summer as is shown on twig D.

Some buds, called dormant buds, do not grow at the normal time after their formation (leaf buds 3 and 4, Fig. 13). Dormant buds act as reserve buds and they will grow if those higher on the branch are destroyed, as may happen by freezing or by pruning, even after a dormancy of one to several years. All buds that grow at their normal period are called active buds.

Buds are of three kinds according to their contents: Figure 13 shows two kinds, leaf buds and flower buds. Leaf buds contain several embryo leaves with very small undeveloped buds, and a very small branch. The flower buds usually have only embryo flower parts. The third type, called mixed buds, contains both leaves and flowers. In many cases the kind of bud can be determined with a microscope as early as July before they open the following spring. Most flower buds of trees can be seen during the winter without magnification. The experienced fruit grower can recognize them by their shape. Since the flower buds begin their development so many months, almost a year before they open, it is clear that cultural treatment to regulate flowering

must be practiced even before the buds appear in order to condition the plant properly. This will be discussed in Chapter 14.

Nearly all leaves are opposite as in lilac or alternate as in elm, but they may be spiral, i.e., on more than two sides. The buds at the base of the leaves have the same arrangement. The position of the buds determines largely the direction of branching and should be considered in pruning and training as explained in the next chapter. Most plants have a bud on the end of the stem, called terminal bud, which is the most active in growth and tends to continue the growth of the stem in the same direction. Side or lateral buds cause branching when they grow. The elm twig has so weak a terminal bud that the last or upper lateral bud usually grows, but in Figure 13 the two last buds grew, making a branch on twig C.

Adventitious buds are those which grow at places other than the axils of the leaves. They may appear on roots, stems, or leaves, and they frequently develop after injuries, such as the removal of a large branch or the topping of a tree. A bud can grow only with dividing cells, but how a plant can develop such cells at unusual places is not known.

When the bud scales fall from a bud they leave individual scars. The terminal bud scale scars are so evident that a series of these marks are called a terminal bud scale scar, which marks the extent of the year's growth. Two are shown on twig D in the above figure, which indicates that the lower end of the stem is three years old.

Plants, such as spirea, which bear flowers on the current growth of the stem may be heavily pruned in the early spring to stimulate the growth of flowering wood. Other plants, such as most fruits, which bear flowers on the previous year's wood will have their potential flowers removed by spring pruning. This may be desirable if they usually bear too much fruit.

The growth of the buds depends on the stored food supply. It is a common nursery practice to cut some woody plants off just at the ground level when they are two to four years old and grow a single shoot from the cut stump. The excess food in the root will cause this shoot to grow as tall as the plant had been, and it will be a straighter, more desirable plant. The great problem is to know when the plant is storing enough food and when it must be encouraged to store more.

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Chapter Nine

PRUNING AND TRAINING PLANTS

Pruning includes the removal of any part of the plant in order to improve its growth for the use of man. There are many reasons for pruning but they will usually fall under three general headings: (1) removal of diseased or injured parts, (2) training for shape, and (3) the improvement of the productiveness of the plant. It should be kept in mind that all pruning is interfering with the natural development of the plant, and, therefore a definite aim should be clearly in mind before any part is removed. After diseases enter a plant as described in Chapter 15 it is often possible to remove the diseased tissue to save the plant, by making a smoothly cut surface for the new healing growth. Likewise, injured tissue should be removed. Most training can be done by pinching off the buds or young shoots when it is evident they are growing in an undesirable direction. In most plants the highest or terminal bud on each plant or on each branch will grow. If this bud is not desirable as a leader, the branch should be removed just above a bud that points in a desirable direction. Pruning for the improvement of productiveness usually involves the removal of larger portions of the plant and will be discussed in more detail under "Balance of Root and Shoot" in Chapter 14.

Training is usually less extreme than the pinching of all the young side shoots or buds, as when a tomato plant is trained to a single stem; or a chrysanthemum is trained in the same way to produce a single large flower. The tomato shoot (Plate II) has two compound leaves below the fruit, with a small undeveloped branch at the lower leaf, and a much larger branch from the next node extending above the

tomato. During the past summer all the buds except one of the lowest were removed from some tomato plants, in order to train them to two shoots per plant. In soil of average fertility these plants averaged more than eight feet in height on their trellis. This method encourages good fruit and it is kept clean. The opposite condition of many branches is produced when the terminal buds are pinched to increase the number and growth of the branches and the production of many small flowers, as on the chrysanthemum. Most plants will respond to training by pinching off the buds or young branches. A study of the elm twig D (Fig. 13) will be helpful in seeing the possibilities of training in the growth of trees. Upright growth would be encouraged by removing the branch and the lower buds of the main stem. Lower, more spreading, growth would result from the removal of the top above the bud on the right and the removal of the branch above its lowest bud. A hedge is pruned to increase the number of branches, therefore the tips are removed, but a fruit tree is thinned by removing lateral branches to encourage the growth of its main branches. Tall, slender, or open plants are formed by the removal of the lateral buds, and bushy plants by the removal of the terminal buds. By a careful study of the position of the buds, it is possible to train plants to grow into unusual shapes along a wall as the French do.

Thinning is actually a kind of pruning except that fruits rather than flower buds are removed. Thus more food goes to the remaining fruits and they grow larger. We usually want the largest yield with the fewest fruits. The fruit is a method of reproduction for the plant and therefore the survival of the species in the wild state depends on the number of seeds instead of the number of bushels of fruit. De-flowering or de-budding is very important in floriculture since an excessive number of flower buds will limit the food to each and result in small flowers. Roses are commonly de-budded.

The removal of old flowers prevents the formation of seed and the waste of much food material.

Suckering is the removal of young shoots that may develop around the base of the stem, as in corn. It was thought

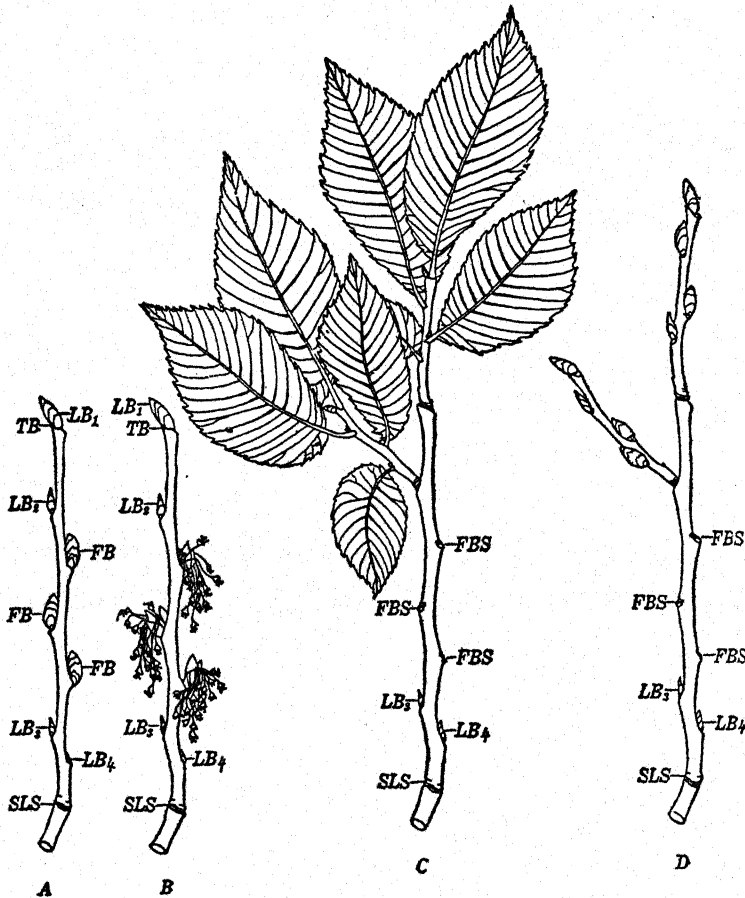


FIG. 13. The seasonal history of an elm twig and of its protected buds. A, winter condition. B, early spring; the floral buds have developed into floral branches. C, mid-summer; 2 axillary leaf buds have developed into branches and produced leaves; 2 have remained latent; the floral branches have developed mature fruits and have fallen, leaving scars. D, late autumn; the leaves have fallen; in their axils are protected leaf and floral buds. TB, minute undeveloped terminal bud; LB₁-LB₄, axillary leaf buds; FB, axillary floral buds; SLS, scale-leaf scars; FBS, floral branch scars. (From Smith *et al.*, Textbook of General Botany. By permission of The Macmillan Co., publishers, 1935.)

that they exhausted the plant but more recently it has been shown that for corn they make as much or more food than they use and that suckering is useless if yield is considered.

Trimming or shearing is a special type of pruning to make a plant or a group of plants look like a wall or cone. In extreme cases they may be shaped like animals. This transfers the attraction from the natural beauty of the plant to that of form. It is difficult to keep such plants in perfect form and otherwise they may be very objectionable.

Although Dr. L. H. Bailey, the great dean of the plant sciences said, "The time to prune is when the knife is sharp," the better plan is to see that the knife is sharp for the pruning time best suited to each kind of plant. The pinching of buds and small branches can be done at any time, and will, if done carefully, control plant growth so that the removal of large branches is rarely necessary. The removal of larger branches should always be done in the early spring toward the end of the dormant season, when the cut surface dries less and the new growth will soon begin the healing process.

The time of flowering should govern the pruning of flowering shrubs. If the flower buds are on the old wood, pruning should be delayed until after they flower, otherwise many of the flower-bearing branches are removed, resulting in sparse flowering. This, of course, is desirable in fruit trees and they are pruned in the dormant season. If the flower buds grow on new wood, i.e., spring growth, a rather vigorous dormant pruning will increase the growth of the new shoots and improve the size of the flowers.

The amount to prune depends on the plant and on the aims of the owner. It has been found by recent experiments that peach and apple trees make larger, quicker-bearing trees if the shaping is done by the removal of buds and small branches instead of the older method of cutting out a large portion of the top each spring. This is probably equally true for other perennials. We usually prune roses heavily be-

cause we want to reduce the number of flowers in order to get larger flowers. Hybrid tea roses are cut back in the fall to lessen their exposure to winds, but the main pruning is given in the spring after the danger of heavy frost is past. The climbing roses are pruned after their spring bloom, which will allow new shoots to develop and store food through the summer. There are some rambler types which are such strong growers that the canes may be removed to within a few inches of the soil. The other climbers should be pruned less vigorously but the best roses grow on the wood of the previous year. The older canes should be completely removed in order to keep the whole top in a young vigorous condition. In all cases of rose pruning the aim is to have the plants out of balance in order to force vigorous shoot growth. It must be kept clearly in mind that two problems face the grower in pruning to improve the productiveness of plants. First is the initiation of flower buds by a proper balance of root and shoot (Chapter 14), and by length of day (Chapter 12). Second is the growth from the supply of food for the flowers or the fruit after the buds are initiated. Both are practiced extensively by greenhouse men and are applicable to most plants in the garden even though conditions are more difficult to control than in the greenhouse. Food results in growth and as more food is sent to an organ more growth occurs. Our largest chrysanthemums are grown on well-fed plants trained to a single stem and allowed to develop a single flower. Fruits may be grown larger, if the same principle is followed. Experimentally, a larger fruit can be grown by ringing the stem just below the fruit. Ringing is the removal of a ring of bark about a half inch wide, by carefully cutting to the wood with a sharp knife. This prevents the movement of food from the branch into the main part of the plant.

Pruning should always be done to leave a smooth surface, cut close to the branch or trunk, and parallel to it. Wounds

of about an inch or more should be painted with a lead and oil paint to prevent infection by bacteria or fungi, which might enter the open pores of the wood and cause the center of the tree to rot. If limbs of two inches or more are to be removed it may be difficult to avoid splitting into the tree. It is best to cut first from the lower side of the branch about one third through, about eighteen inches from where it is to be removed, then about six inches farther out cut from above until the limb breaks off. Now the stub can be removed close to its base with no danger of splitting to injure the tree.

Pruning stimulates the growth of buds below the cut as has been suggested above. All terminal buds appear to secrete a hormone which descends and inhibits the growth of the buds which receive it, causing them to remain dormant. When a twig is removed the first bud back of the cut will cease to get the growth-inhibiting hormone and will begin to grow. It is for this reason one can so easily determine the shape of a plant by judicious pruning. Simply expect the topmost bud to grow in the direction it is pointed. Trees may be trained to fill in sparse areas of their branching by pruning a little more heavily on the strong side and leaving buds which point toward the weak sides.

Pruning appears to increase the vigor of a plant. This is a balance of root and shoot problem, and therefore means that the reduction of the top decreases the supply of carbohydrates to the point where nitrogen is available in excess. High nitrogen favors the growth of the protoplasm for larger, thin-walled cells, resulting in more rapid growth. If more new growth is desirable it is safe to try pruning more heavily. It is clear from this and the preceding paragraphs that it is unwise to prune a plant heavily in late summer because the growth so stimulated would be tender and therefore in danger of winter-killing.

Tree surgery is rapidly becoming a respected profession because more and more science is being applied. Tree "sur-

geons" should be chosen with great care and should be impressed with the fact that plants should be treated for permanent vigor and natural growth, and not for quick results gained by the use of stimulants which might be harmful. Too high nitrogen may appear to be very beneficial for a few months, but it may cause an earlier death of the plant. To prolong the lives of trees, decays and injuries can usually be repaired by tree surgeons, who remove infected areas and treat the cavities to prevent further infection.

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Chapter Ten

PROPAGATION

Seed-plants must be propagated, because they, like animals, get old and die. Other plants, which never produce seeds, such as mosses and ferns, may be killed by animals, fire, or cold but do not die of old age. They continually make new growth at one end and die at the other end; however, they too have the power to produce new plants from sexual and asexual methods of reproduction. It is a simple matter to dig the underground stem of a fern, as the bracken, where the growing point is just ahead of the leaf, and several feet back of the leaf the stem is dead, while farther back it is decayed. In fact some of our living moss and fern plants may be much older than our oldest trees.

Propagation may be sexual, that is by seeds produced through flowers, or asexual by a number of methods which promote the development of new plants from root, stem, or leaf sprouts. Other natural methods will suggest themselves as we discuss artificial propagation.

Sexual reproduction is the production through the seed of a new plant which began when the male sex cell fused with the female sex cell. Chapter 18 will make clear how a single plant produces many combinations of its characteristics in its sex cells. Furthermore, it is not necessary that the pollen grain come from the same plant that bears the female part of the flower but only from one of the same kind of plant (cross-pollinated). Thus, plants grown from seeds will resemble their parents but will vary widely in smaller details because of the many combinations of their parents' characteristics, just as sisters and brothers are all different. In many cases, where quality is the result of an exact combination of char-

acteristics as in most of our tree fruits, plants produced by sexual methods yield a very inferior quality of fruit.

Asexual methods of propagation all differ from sexual, since the offspring is grown from a group of cells from one plant and, therefore, has always exactly the same protoplasm or germ plasm as that of the parent. This is possible because a small portion of a plant can regenerate a complete plant. A bud always arises by the division of cells as described in Chapter 4, and therefore has exactly the same gene combination. Thus any number of cuttings or grafts made from the same plant will produce plants that are the same in all their general characteristics. For this reason fruits, roses, and many trees are usually propagated by some asexual method. Such a group of plants produced asexually from a plant is known as a clone.

It is clear from the above that for plant breeding the sexual methods of propagation will give a wide variety of plants. This is covered more fully in Chapters 18 and 19. If uniformity is desired some asexual method of propagation, such as cutting, grafting, budding, or layering, must be utilized.

A cutting is a small piece cut from a stem, root, or leaf, which will produce a complete plant like the one from which it came. Cuttings must form a root-promoting hormone, before roots are initiated, which may require only a week or, for some plants, it may take as long as several months. During the last two or three years a number of chemicals have been found which appear to stimulate the hormone formation or perhaps to act like the hormone (Plate X). This is discussed more fully in Chapter 20.

Stem cuttings are of two kinds, dormant wood and green or growing wood cuttings. They must be from healthy tissue, usually four or five inches long, with one or more buds and a good supply of stored food. Dormant cuttings are made in the fall and stored in a cool moist place until early

spring, when they are planted, but kept cold enough to retard bud growth until the roots are well developed. Sometimes they are buried in the garden deep enough to be below the frost line. Green wood cuttings may be made during the summer, but since transpiration is likely to be excessive, part of the leaf surface should be removed and the cuttings should be shaded and should be sprinkled gently often enough to keep the surface moist. In greenhouse propagation cuttings are shaded and sprinkled once to several times a day.

Cuttings must have a good set of roots to produce good plants. The same four closely related conditions must be considered for cuttings as was described for growing seedlings, namely: plenty of stored food, adequate oxygen, moisture, and temperature. It has been found that cuttings made from tissue with a good supply of stored food will use it in better rooting and in growing a stronger plant. They need extra oxygen to oxidize the food and so are usually set in sand. This can be kept well moistened but still remain well aerated. Bottom heat is beneficial to hasten root growth when started on a greenhouse bench. They should be restricted from excessive transpiration, but some air circulation may be necessary to avoid the growth of damping off fungus. Most cuttings root better if they are made at right angles instead of long tapering cuts.

Root cuttings may be used from plants that sucker naturally from the root. Raspberry and blackberry root cuttings are frequently made about two or three inches long from roots about as thick as a pencil. The cuttings may be made by taking a piece of root with a small sucker. Root cuttings should be planted very shallow to allow the bud to reach the surface quickly and begin to make food.

Grafting is the placing of a cutting of last year's growth called the scion into another plant called the stock in such a manner that like tissue will grow together and become a single plant. There are several kinds of grafting, but they

all depend on getting the cambium layer and a small portion, at least, of the phloem and the xylem in such close contact that the new growth will form a union through which food and water will be translocated. For this reason, only plants with a well-developed cambium are grafted, usually woody plants. The scion carries the variety of plant, or we may say the protoplasm which we want in the new plant, and therefore always remains like the original plant, while the stock is usually chosen because of its vigorous or disease-resisting root system. Grafting is usually done near the end of the dormant season. Care must be taken to avoid the loss of moisture from the scion before or after grafting. Grafting wax is often used to cover the wounds of the scion and stock to prevent drying.

Grafting is used for many reasons: (1) it is a very common nursery practice because it offers a simple means of enormously rapid propagation of a good variety. Many of our best fruits have come from a single tree and in some cases from a single bud sport of a tree. (2) A plant breeder working with tree fruits can cross the flowers; then he can plant the seeds and after one year's growth use the whips as scions and graft them on an older tree. In this way they will bear fruit in less than half the time necessary for the growth of a tree and much space is saved. (3) It enables people with limited space to have as many varieties of apples, pears, or cherries on a single tree as they wish. It has been reported that Burbank had more than six hundred of such grafts on a single plum tree. (4) The fruit of an older tree may be changed to a more desirable variety by grafting on a number of its branches.

Root, tongue, or whip grafting is done by selecting the stock and the scion of nearly equal diameter and cutting with a sloping cut, about an inch long, then splitting each longitudinally so that they fit together, after which they should be bound snugly with waxed thread to hold them in place until

a union is made (Plate IV). The greatest care must be taken to have a long union of the cambium and other like tissues. Seedling roots which are often used permit two or three stocks to be made from each. The scion should have two or three buds.

Cleft grafting is usually done on older branches where the scion is inserted in the one side of the split end of a stock cut at right angles. Here again the cambium of one side of the scion must be in line with the stock cambium (Fig. 14).

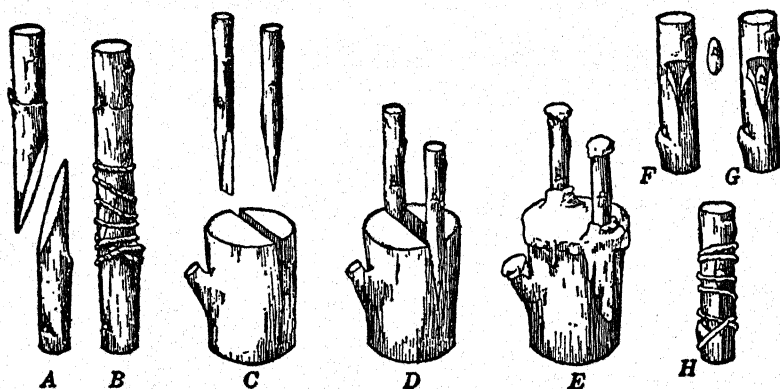


FIG. 14. Methods of grafting. A, B, between stock and scion of similar size. C, D, E, between a large stock and small scions. F, G, H, bud-grafting. (From Smith *et al.*, Textbook of General Botany. By permission of The Macmillan Co., publishers, 1935.)

One, two, or more scions may be put in the same stock. The best-shaped plant will result later if only one is allowed to grow on a stock a little larger than the scion.

Budding might be considered a form of grafting since a single bud with some bark and a little wood (in some cases the wood is removed) is placed in a slit of the bark of the stock plant so that the cambium will unite and grow phloem and xylem in the union (Fig. 14). This method is used commonly with peaches and roses. It is very important to keep the buds in a natural fresh condition until used. Budding is generally done low on the plant, that is about the ground level or just below, in early summer while the bark can be

slit back to enter the bud against the wood. Frequently buds develop several years later from the stock and unless they are destroyed may rob the budded portion of food and kill it. In all cases of grafting and budding wound hormones are probably formed to stimulate rapid cell division. Only varieties that will readily form a strong union of the new tissue should be used for scion and stock. We do not know why all woody plants cannot be grafted on each other, as for example cherry on apple, but we know the tissues will not unite.

Layering is a method of propagation similar to cuttings except that a shoot or branch is held against the ground or even covered at places with soil until roots grow, before severing it from the parent plant. Cutting through the bark often hastens rooting. Roots will usually grow opposite each bud as it develops a shoot, after which the cuttings may be made. This method is more successful with plants that root poorly.

Runners may be formed naturally, as in strawberries, and the new plants transplanted when they are well rooted. This is a form of layering.

There are several forms of propagation among the plants that have bulbs, corms, rhizomes, tubers, etc., but for these, special reports should be consulted.

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Chapter Eleven

LEAF STRUCTURE

The leaves are outgrowths of the stem, consisting, usually, of a slender stalk, the petiole, frequently having at its base small appendages called stipules, and the broadened conspicuous portion called the blade. The leaves begin to develop in the buds by the protrusion of a small portion of the dividing tissue of the stem tip. All the leaf cells retain this ability to divide for some time, so that a leaf grows in every region. For this reason repeated spraying is necessary to keep the growing leaves covered.

Leaves are of many shapes or forms, but two general classes should be considered. Simple leaves, such as the zinnia, have the blade in one piece. In compound leaves the blade is completely divided into leaflets, either pinnately as in the tomato (Plates I and II) or palmately as in white clover. Thus, to determine which are simple leaves on a branch and which are compound leaves you must distinguish between petiole and stem. A stem ends in a more or less conspicuous bud, which never occurs at the tip of a compound leaf.

The veins of leaves consist of strengthening tissues and conducting tissues which are continuations of the conducting tissues of the root and stem, and they function in the same way. They branch and rebranch until the entire leaf is penetrated with a microscopic network of the cells of conduction. They are divided into two classes: parallel venation when they run in nearly parallel lines, as in grasses; and net venation when they branch in many directions, as in most broad leaves.

The epidermis is the outer covering of the leaf, consisting of a single layer of flattened cells on both sides of the leaf.

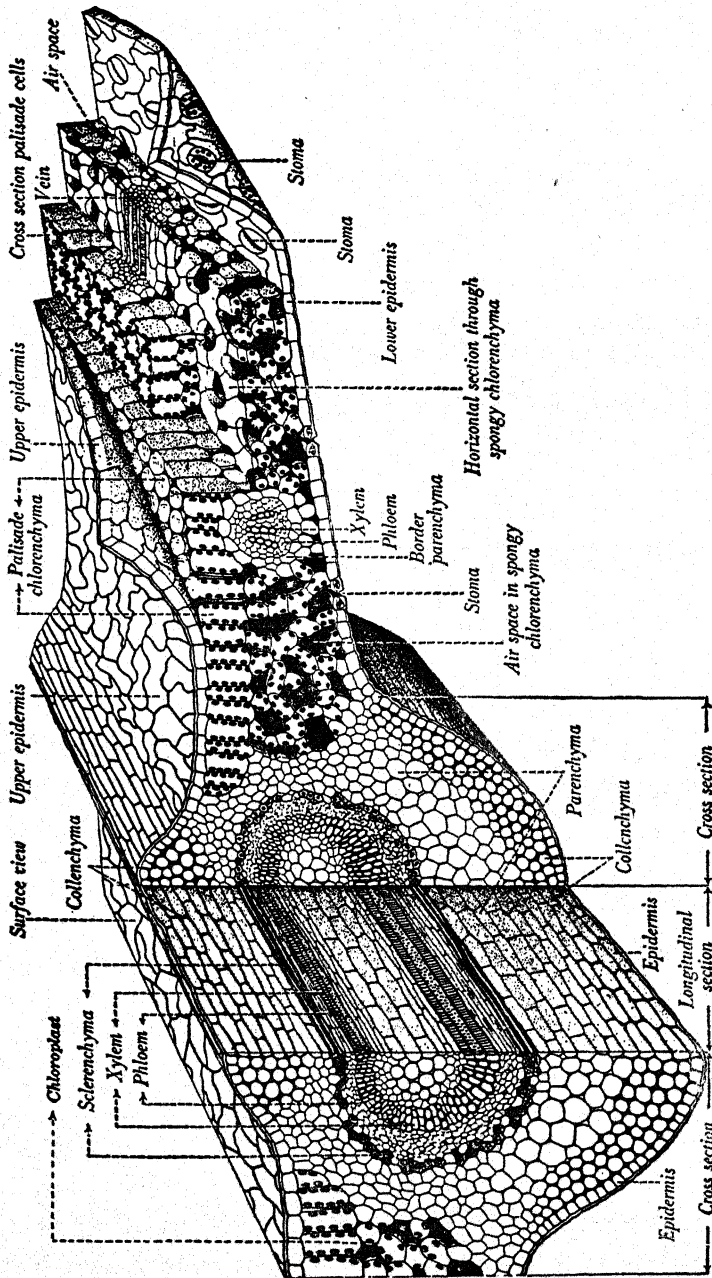


FIG. 15. A section of midrib and a small part of the leaf blade. On the left is a cross section of half of the midrib followed by a longitudinal section, and this by a cross section of the remainder of the midrib and a portion of the blade. The leaf blade on the right is dissected in various ways to show cell arrangement and the intercellular spaces. (From Brown's The Plant Kingdom, Ginn and Co., 1935.)

Figure 15 shows a leaf highly magnified to make clear the relative size, shape, and arrangement of its cells. The epidermis has three chief functions: first, to protect the inner cells of the leaf against mechanical injury, for which it has tough surface walls, supported in most leaves by more than a million walls per square inch; second, it prevents the excessive loss of water, for which it has a layer of a waxy substance called cutin on the outside; and third, it must allow the gases necessary for photosynthesis and respiration to enter and leave the leaf. For this purpose it has many small openings called stomata, which make continuous channels for the air from the atmosphere to the air of the intercellular spaces of the leaf.

A stoma is a small opening made by two curved cells (see Fig. 15) called guard cells. The walls facing each other are thicker than the remainder of the wall of each guard cell. When they absorb water the pressure causes more expansion of the thinner walls than of the thicker walls, in such a way that the opening becomes larger. When a guard cell loses water the stoma gradually closes as the pressure within the guard cells decreases. When soil water is deficient this may continue until the stoma is entirely closed.

The guard cells, which contain chloroplasts and make sugar, have more concentrated contents than the epidermal cells, which do not have chloroplasts. This difference causes the water to diffuse to the guard cells, and so maintains a high pressure in them during the day, except as explained above. At night most stomata close for at least a part of the time, and some of them remain closed all night.

Stomata vary in size, distribution, and number, but are always microscopic, and may be as small as one-ten-thousandth of an inch wide and five times as long. A very common size is three to five times the size just given. The total area of stomatal openings is usually about one to two per cent of the leaf area. Recent researches have shown that

gases diffuse through small openings similar in size and arrangement to stomatal openings almost as rapidly as they do through single openings the size of the entire leaf.

Some leaves, notably tree leaves, have all their stomata on the lower surface. Most of our herbaceous plants have more stomata on the lower than the upper surface; a few have them about equally distributed on both sides; and a few, such as water lily, have them only on the upper surface.

The number may vary rather widely on the same plant, under different conditions, but the variation in number is much greater among species, as indicated by the following table (from original data and from the references at the end of the chapter) giving general average numbers of stomata per square inch of leaf surface for some of our common plants:

<i>Plant</i>	<i>Upper surface</i>	<i>Lower surface</i>
Spanish oak	0	750,000
Scarlet oak	0	650,000
Red oak	0	425,000
White water lily	287,000	0
Sunflower	110,000	200,000
Apple	0	190,000
Rose	0	62,000
Common pea	63,000	135,000
Petunia	62,000	87,000
Tomato	62,000	131,000
Zinnia	75,000	137,000
Potato	33,000	104,000
Corn	45,000	57,000
Oats	26,000	28,000

It should be remembered that all molecules tend to diffuse from regions of relative abundance of one particular kind of molecule to regions of relative scarcity. This explains the movement of the three kinds of molecules through the stomatal openings. The carbon dioxide is used in the leaf in photosynthesis, the oxygen is given off in the same process (see Chapter 12), and the water is lost from the humid air of the air spaces in the leaf to the atmosphere

(transpiration, Chapter 13). Plants must have the carbon dioxide and discharge oxygen but the loss of water seems to be unnecessary, and when the soil is dry may be very dangerous. The stomata may close under such conditions, preventing the diffusion of all molecules. In this way the lack of water in the plant prevents its food-making, and during a prolonged dry period, may reduce materially the plant's growth.

A knowledge of stomatal distribution and action will be seen to be important in a number of chapters but particularly in Chapter 15 on spraying for protection against disease.

The mesophyll of the leaf includes all the cells between the upper and the lower epidermis, except the cells of the veins. Most leaves have one or more layers of elongated palisade cells next to and at right angles to the upper epidermis. The remainder of the mesophyll consists of more nearly spherical cells and is called the spongy tissue.

The chloroplasts are small portions of the protoplasm containing the complex green pigment called chlorophyll. They are more abundant in the palisade cells than in the spongy cells, but are always in the periphery of the protoplasm. Many leaves have more of them than the one in the illustration. Although they are fewer in shade plants, they are so numerous that the leaf appears to be a solid green, but by looking at small sections with a microscope the individual chloroplasts may be clearly seen. All the photosynthesis takes place in the chloroplasts.

Starch grains are the storage form of the sugar made in photosynthesis and are abundant in the leaf while the sun shines. At night much of the starch is changed back to sugar and translocated to other parts of the plant. A leaf may be tested for starch by removing the chlorophyll by dissolving it in hot alcohol, and putting iodine solution on the colorless leaf. If it has starch it will turn a dark purple color.

The intercellular or air spaces of the leaf are very exten-

sive. Every cell is said to have part of its surface next to an air space and the total exposed surface of all the cells inside the leaf is from five to thirty times as great as the total of the upper and lower surfaces of the leaf. Examination of Figure 15 will give an idea of these surfaces. More surface per unit of volume has been found in the palisade than in the spongy portion by Turrell, who has contributed much to our knowledge of the internal structure of leaves. This surface is very important in the absorption of carbon dioxide from the atmosphere by the cells. The carbon dioxide diffuses from the atmosphere through the stomata into the intercellular spaces, from which it is absorbed by the water on the walls of the cells and diffuses into the cells. When the atmospheric content of carbon dioxide is considered, its rate of entry into the cell can be explained only by the fact that the stomata are very numerous and the area of cell walls exposed to the air spaces in the leaf is so much greater than the surface of the leaf.

There are a number of modifications of leaves which are of interest. Each flower is a *group of leaves* so different that we give them their special names. The leaves that are submerged in water are usually without an epidermis or stomata; obviously there is little need for protection against the injury or loss of water. Water plants die quickly when placed in the air. Some plants adapted to dry conditions, such as some of those selected for rock gardens, store quantities of water in their leaves, the central portion of which contains large cells to hold water, but few or no chloroplasts. The insectivorous plants have leaves which catch insects and secrete an enzyme which digests them. It is believed to be a valuable source of nitrogen for them. The pitcher plant has a hollow leaf containing water in which insects drown, after which they are digested. The Venus' fly trap catches insects between two flaps of the leaf which come together when they are touched on their trigger hairs by the entering

insect. Many others might be mentioned. Some of the desert plants, as cactus, have the leaves reduced to small spines.

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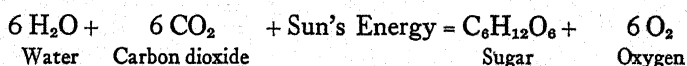
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Chapter Twelve

FOOD MAKING

Photosynthesis, commonly called food making, is a plant process by which, when light falls on active chlorophyll, sugars are made from water and carbon dioxide, with oxygen given off as a by-product. Since it is the only source of supply of two essential substances, food and oxygen, it is impossible to explain in terms too extravagant the importance of this function of plants. Without photosynthesis we can see no way for any form of life to exist over a period of time. Energy from the sun is caught and stored in the sugar or other carbohydrate material, and can later be used as food by animals for their growth or as a source of their energy. The oxygen, without which life cannot exist, is released to the atmosphere in quantities large enough for all its many uses on this planet.

Chemically it is expressed:



The water enters the plant through the roots and reaches the leaf through the conducting system of the stem and leaf petiole. The carbon dioxide enters the leaf from the air by diffusion through the open stomata and then enters the leaf cell by absorption into water from intercellular spaces. The sun's energy is absorbed by the chlorophyll, but the exact way in which the energy is used to make sugar is not known. Only about 3 per cent of the energy falling on a leaf is used in photosynthesis. Some of the light is reflected and some is transmitted, but only the light absorbed by the chloroplasts (shown in the leaf, Fig. 15) can be used by them. The oxygen, shown in the chemical formula to be equal to the amount

of carbon dioxide used, diffuses from the cell to the inter-cellular spaces and then through the stomata to the atmosphere.

The sugar is truly the food material of the living world. All animals, and all fungi, as well as green plants, depend on it as their basic food. The plant can convert the sugar into starch for storage, or it may use it to make the cellulose material of which the cell walls are made, and in trees become lignified to make all the wood of the forest. By the addition of small amounts of nitrogen and a few other elements, the proteins are made from sugar (Chapter 23). Fats are similar in structure to sugars, but many of the details of their synthesis, from sugars, remains a mystery.

About two hundred years ago it was believed that plants grew from air and water. It seems nearly true even today because many plants such as lettuce, apples, and cucumbers, to mention only a few, consist of more than 90 per cent water and about 9 per cent of the products of photosynthesis. All plants consist largely of water and sugar or its products. The corn studied by Miller was about 98.5 per cent water and air. His analysis showed about 69 per cent water, 29 per cent material of photosynthesis, and about 1.5 per cent of the elements taken from the soil. Water is so often a limiting factor in growth that we cannot stress too much the importance of having a favorable water supply and conditions favorable to photosynthesis.

It is difficult to measure the rate of photosynthesis or to measure the amount of sugar made because the plant uses it continuously. The best estimates are between a half an ounce and an ounce per square yard of leaf surface per day under favorable conditions. This seems like a small amount but if one considers the number of days it takes place and tries to measure the number of square yards of leaf surface in the lawn or on a tree, which is much more than the surface area of the ground covered, it becomes more evident that the

total product of photosynthesis is very great. It has been expressed in a number of ways. It would appear as a staggering amount if it should appear as sugar in our trees or on our lawns. Transeau has figured that an acre of corn makes about 200 pounds of sugar per day and an acre of apple trees about 93 pounds per day. Sugar cane and sugar beets produced thirty-two million tons of sugar in the 1930-1931 crop season, to which must be added the sugar used to build their plant bodies. Dr. Arthur has estimated that the human race uses about 0.2 per cent of the product of all photosynthesis as food, and all animals great and small use less than 2 per cent. The other 98 per cent is destroyed by bacteria, other fungi, and fire.

The gardener must depend on a high photosynthetic rate to be successful. He can improve many of the necessary conditions but he has no power over many of the other governing factors, such as temperature and sunlight. Many experiments with the different colors of light indicate that plants can use any one color successfully in photosynthesis, but that the red and blue are slightly more effective. He can give the plants enough space to come in direct sunlight by avoiding overcrowding. He can make use of the season of the year when the temperature is best. Some measurements have been made which show photosynthesis may go on three times as fast at ninety degrees as it does at sixty degrees temperature, while for other plants, as potatoes, seventy degrees F: has been found to be optimum. In some cases the rate may be doubled with an increase in temperature of ten degrees C. The soil fertility may be improved. Nitrogen may be applied in excess at an early stage in order to grow larger leaves to be exposed to the light; this is often spoken of as "giving the plant a quick start." An optimum soil moisture content will enable the stomata to remain open, admitting the maximum amount of carbon dioxide. This is accomplished with greatest success in some of the irrigated regions, as indicated

by the large yields of crop plants. Occasionally some pruning may be necessary to allow adequate light to reach all the leaves. A number of good soil practices will favor root growth and increase the photosynthetic rate.

Shade-loving plants differ from sun plants in their structure and in their ability to use sunshine. They usually have thinner leaves, fewer chloroplasts, but larger leaves. The chlorophyll appears to be more economical in its use of sunshine or diffused light when the intensity is low. Many of the ferns and other shade-loving plants may reach their maximum rate of photosynthesis with a light intensity of less than 40 per cent of full sunshine, but in a stronger light their transpiration becomes excessive. Such plants are able to store food and make normal growth in the shade. If a sun-loving plant is grown in the shade its leaves are larger and thinner than normal, in fact it develops the structure characteristic of shade leaves, but its internodes are longer and its rate of photosynthesis is too low to produce food for adequate storage. This difference in storage material of sun plants and shade plants grown in the shade enables the shade-loving plants to crowd out the sun plants.

The amount of carbon dioxide in the air is very small in comparison with the other components.

Average percental composition of air:

Nitrogen	78.0
Oxygen	21.0
Carbon dioxide	0.03
Other gases	0.97

It will be seen that the plant must get its carbon dioxide from air in which there are only three parts in 10,000. It has been shown that by increasing the concentration of carbon dioxide the rate of photosynthesis under most conditions will increase, as the concentration of carbon dioxide is increased to at least ten times the atmospheric content. For this reason it has been felt that the total world rate of photo-

synthesis has been greatly reduced by a decrease in carbon dioxide content and in turn this restricts the amount of oxygen in the atmosphere. Increased carbon dioxide has been tried in greenhouses but the cost has been too high to make its use profitable, in spite of increased yields. It is quite possible that a cheaper source will be found so that it can be profitable to increase the carbon dioxide content for some crops.

The large area from which the carbon dioxide must come to supply the plant is most astonishing. If a sunflower leaf derived all its supply of carbon dioxide from the air directly above it, the entire carbon dioxide content would be used from an eight-foot-high column of air in one hour. If all the carbon dioxide used by a crop of corn were derived from the air over the field about 40 per cent of the total amount over the field would be used. It must be kept in mind that plants (weeds or cultivated plants) cover most of the warm, humid parts of the earth, using carbon dioxide at comparable rates.

The formula on page seventy shows that plants give off an amount of oxygen equal in the amount of carbon dioxide used in photosynthesis. All other organisms give off carbon dioxide and use oxygen in their respiration. (Plants, too, give off carbon dioxide in their respiration, but only during the night, in the absence of photosynthesis, do they discharge it to the atmosphere in excess of its use.) When all animals large and small are thought of as giving off carbon dioxide, the amount seems stupendous, but it has been said that plants use all this and about fifty times more, which comes from fungi, bacteria, fires, volcanoes, etc. Someone has estimated that a plant with 150 square yards of leaf surface will use all the carbon dioxide given off throughout the year by one man, and at the same time supply his need for oxygen by its release in photosynthesis. A large tree may have 5,000 square yards of leaf surface.

Garner and Allard published their original investigations,

in 1920, on the effect of the length of day to the growth of the plant into a vegetative condition or a reproductive condition. They shortened the day by putting the plants in the dark for a part of the day, or lengthened it by using a small electric light. Many other workers have studied length of day effects, or photoperiodism, as it is called. Many plants have been studied, and among the many discoveries it has been found that a very weak light, less than thirty-watt bulbs at six-foot centers, inadequate for reading, is sufficient to make the plant respond to long-day conditions. Such a light is less than one-five-thousandth of the intensity required for optimum photosynthesis but it is all that is necessary to have the effect on the plant of a lengthened day. Even more striking, the weak light must fall on only a few of the young growing leaves to cause the whole plant to show the response to the increased period of light.

Long-day plants are those that bloom normally in mid-summer or with light for twelve hours or more, such as hibiscus, radish, or lettuce, while with a short day these plants remain vegetative indefinitely. If radishes are planted in the greenhouse in midwinter they will form good roots but will not flower; however, if an electric light is used to extend the light period by four hours each day they will form flower stalks but very small edible roots. Short-day plants bloom normally with a short day, but remain vegetative with a long day. These plants include many of the spring and fall flowers, such as ragweeds, cosmos, and scarlet sage. The photograph (Plate V) shows the relative growth and flowering commonly found with long and short days. Other plants, such as the ever-bearing roses, are indifferent to the length of day and will reproduce under all day lengths. The response to length of day has a profound influence on the development of plants, showing that the functions of growth and reproduction go on with different sets of conditions, but not at the same time. Plants may grow vegetatively to

become giants or they may flower while very young and only a small fraction of their natural size.

This is one of the methods used by greenhouse people to regulate the time of flowering of those plants that would otherwise bloom in certain seasons. It has always governed the time of planting such crops as lettuce, corn, wheat, etc., but the reason for the time requirement was not known. By regulating the length of day, greenhouse people control the time of flowering of those plants that would otherwise have seasonal bloom and plant breeders force plants that would ordinarily flower at different times to flower at the same time for cross-pollination. Such plants as some varieties of potatoes and Jerusalem artichokes respond to length of day by storage of more food in their tubers with a short day. Bulb and stem growth in some plants responds in a similar way.

The reason for length of day phenomena is not known. It is not a matter of quantity of light since the light necessary is far below the minimum amount for photosynthesis, but rather a matter of the number of hours. For this reason the discussion may not belong in a chapter on food making, but it is possible that some unknown substance is made which can be considered a food. A difference of less than half an hour in day length at the critical point will determine the growth into flowering or continued increase in size.¹ Much work has been done on the problem, studying such fields as nitrogen assimilation, temperature, stored food, and growth hormones, but at present the problem remains unsolved. The fact that a whole plant responds to an increase in the light period for a few of its growing leaves, strongly suggests it to be a hormone reaction.

¹ At the present time experiments are in progress at the United States Department of Agriculture's experiment station at Beltsville, Md., to perfect the discovery they made by which the short-day fall-blooming chrysanthemums are prevented from blooming by giving them a short period of light in the middle of the night. It is possible that ten minutes of a low light intensity each midnight on these October-blooming plants will delay them until January or February. But the interesting part is that they can be brought into flower any time during this period by discontinuing the artificial light.

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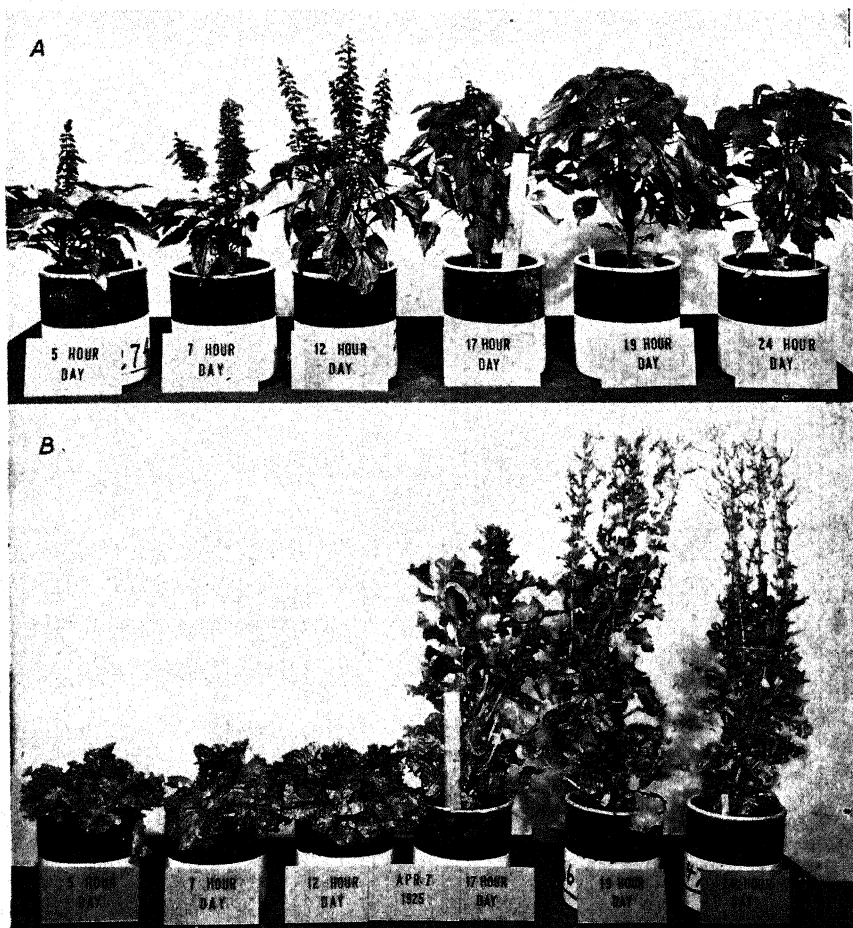


PLATE V. Effect of length of day on plants. A, scarlet sage (*Salvia splendens*), a short-day plant; B, lettuce, a long-day plant. The day lengths to which the plants were subjected are indicated on the pots. (From Hill, Overholts and Popp's Botany, McGraw-Hill Book Co., 1936.)

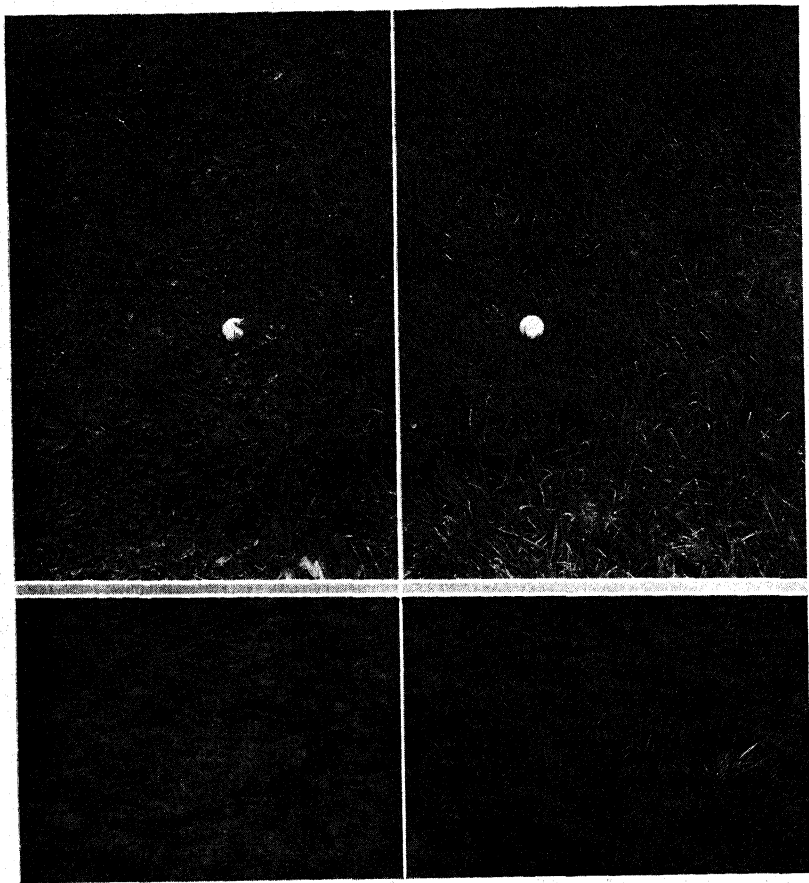


PLATE VI. *Top.* Reduction of weeds and increase in density of an established Kentucky bluegrass turf (right) after application of 6-12-4 fertilizer at the rate of 4 pounds of nitrogen to 1,000 square feet. *Below.* Kentucky bluegrass fertilized (right) previous to seeding in the fall with bonemeal. Picture was taken in April following to show early improvement. (From United States Golf Association Green Section.)

Chapter Thirteen

TRANSPIRATION

Transpiration is the loss of water by plants through the process of evaporation and simple diffusion. Under most conditions more than 90 per cent of the loss is from the leaves and the remainder from the stem, chiefly from the younger portions. Transpiration used to be considered valuable to the plant to carry salts into the plant and through it. This would be true if plants had large openings through which the soil solution flowed; however, since the water enters, not as a stream, but as individual molecules and the salts enter as molecules by diffusion independently of the rate of water intake, it seems impossible that transpiration is necessary for salt absorption. Although numerous experiments have shown that the rate of transpiration and salt absorption are not dependent on each other, it is possible that the movement of water inside the plant speeds the movement of salts after they have entered the plant.

Many experimenters have attempted to show the influence of transpiration on these problems, but so many factors are interwoven that the results are variable. To illustrate: Dr. Hasselbring grew tobacco plants in two groups, one of which he grew under a cheesecloth shelter which reduced the transpiration by 25 per cent. The two sets attained an equal dry weight but those with the lower rate of transpiration absorbed about 15 per cent more salts than the other set. Other plants under slightly different conditions have absorbed a little less salts with retarded transpiration. In view of such conflicting results, it is generally believed that transpiration itself is a useless phenomenon which the plant cannot avoid because of its need for the diffusion of other gases to and from the leaves.

The amount of water transpired by growing plants is large. A single tomato, sunflower, or corn plant has been shown to absorb about four hundred fifty pounds of water (the equivalent of a large barrel), but all of this large amount is transpired during its life except about 1 per cent which remains in the plant at maturity. This is equivalent to three or four quarts per plant per day, during periods of high transpiration. An acre of corn or grass must frequently give off water in transpiration in excess of two tons per hour during the warm part of the day. Corn has been shown to use from eleven to fifteen inches of water or rainfall to grow a crop.

Some measurements have shown the transpiration rate to vary by several hundred per cent on succeeding days depending on the conditions of the plant and the environment of the roots and the leaves. Many of the natural laws of physics and chemistry have an important influence on the transpiration rate. A rise in temperature increases the rate of evaporation of water; the speed of the diffusion of water molecules through the protoplasm, the cell walls, and the air spaces in the leaf; and the water-holding capacity of the air.

Light increases the transpiration rate in several ways, perhaps chiefly by increasing the temperature, but also by causing the stomata to remain open, and by supplying the energy actually used in the evaporation. Ninety per cent or more of the water lost in transpiration is lost during the day. The rate increases rapidly during the morning hours and usually reaches a maximum shortly after one o'clock, but the afternoon rate is usually lower than the morning rate. During the night absorption is faster than the loss and the cells regain their turgidity. In the morning the rate of water loss is faster than the rate of absorption and the amount in the plant cells is reduced causing a greater concentration of the cell sap, which retards the rate of evaporation and the loss from the leaves.

Gentle winds of three to ten miles per hour increase the rate of transpiration markedly, by carrying the moisture from the surface of the leaf as fast as it diffuses through the stomata, but further increases of wind velocity have little effect.

The transpiration rates that are highest and most likely to cause serious damage are brought about by a combination of conditions such as occurs in the summer; high temperature, bright sunshine, and winds. If the soil has plenty of moisture the plants that are well established and are adapted to our conditions can withstand even our most drying conditions. Occasionally in the Middle West where the temperature may be higher, the humidity lower, and strong winds blowing, the plants have been killed even with adequate soil moisture.

More than 90 per cent of the moisture is lost from plants through the stomatal openings of the leaves and young stems. As explained in Chapter 11 they close and the plant wilts when the turgor pressure is reduced to zero or nearly zero. Their closure is gradual and diffusion is of such a nature that it is not retarded until they are more than half closed. This slow method of regulation may save the life of the plant by preventing its desiccation, but wilting also retards the growth by reducing the food supply, hence it is better practice to regulate the soil moisture instead of expecting stomatal regulation of the loss of moisture.

The water requirement of plants is the relation of the water absorbed by the plant during the growing period to the dry weight of the plant. It is a unit of water economy. Plant species differ quite widely in this respect under uniform conditions, and the same species differ widely as the conditions vary. The water requirement for a number of plants was determined by Briggs and Shantz. A few of the approximate values follow: sorghum 280, corn 350, wheat 480, oats 600, alfalfa 820, ragweed 950. These large figures mean, for

example, that for every dry weight pound of oats, the plant has absorbed six hundred pounds of water. Most of this has been lost in transpiration. These figures vary widely from year to year and with the locality because of the variation in the environment. Of all the causes for variation in the water requirement of a single species perhaps weather conditions are most important. If the conditions for high transpiration prevail when the plants are large they may lose enough water in a week to give them a high figure for the year. Plants use less water in comparison to their growth and therefore have a lower water requirement if they have about optimum soil moisture, but too dry or too wet a soil slows the growth of the plants and causes a higher relative water requirement. Plants grown in a fertile soil develop bigger plants and have a lower water requirement than those grown in a poor soil. Plants grown in a higher humidity have a lower water requirement than those grown in a lower humidity. This study has never been done extensively with trees nor with the garden plants. The comparable water requirement for trees would be exceedingly important as a guide in selecting shade trees because of the difference in their competition for water in the garden. Observations indicate that shallow-rooted trees require more water than deep-rooted ones, but this may be because the latter remove much of their water requirement from below the root level of the lawn or garden plants.

Transpiration and soil moisture are closely related. When the soil moisture is low the transpiration rate is low and growth is slow; when soil moisture is optimum, transpiration is high and growth is good. It must be remembered that the soil is able to hold several inches of the winter rainfall to be used to supplement the summer rainfall during the growing season. Recently the Soil Conservation Service has determined a soil moisture below which it is unwise to sow wheat in some of the wheat growing states. They depend on using a definite part of this reserve moisture and know that with

a normal rainfall a profitable crop will result in an average year.

Plants should be watered copiously but not frequently in order that the water may soak some distance into the soil to supply the deeper roots as well as the shallow ones. Most soils respond more quickly and yields are increased more by keeping optimum water content than by any other factor. Since deep roots grow most readily through the air-filled spaces in the soil watering should be delayed for most plants until the available water has been depleted or until they begin to wilt during the hottest part of the day. Many plants will yield more and better flowers and fruit if allowed to reach a low soil moisture for short periods.

As explained in Chapter 7 water penetrates the soil only as the field capacity is reached in the soil above. The most economical way to water is to bring a considerable depth of the soil to field capacity, because the roots grow more rapidly in optimum conditions of moisture and air. Frequent light watering encourages the growth of a poor root system of shallow roots. A plant should have a root system in contact with a large volume of soil to supply water and mineral food (see Fig. 8). Most soils should have an inch or more of water applied at a single application, following which the plants should need none for a week. It is more economical of water to apply it copiously but less frequently than to water every day, since less is lost in evaporation.

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Chapter Fourteen

BALANCE OF ROOT AND SHOOT

For the plant lover this is the most important principle in the entire book, since it might be considered a summary of all the principles of plant growth, but at the same time it is also the most difficult to understand fully and to control properly. The balance is one of function rather than structure, but it is actually a true balance. It will be recalled that the function of roots (Chapter 5) is the absorption of water and mineral salts, and the functions of the shoot (leaves and stem) are the manufacturing and conduction of food (Chapters 8 and 11). Conditions do not remain constant and therefore the balance cannot be perfect at all times as might be illustrated by the absorption and loss of water. A perfect balance of this function would mean a steady rate of absorption and a parallel steady rate of transpiration. As has been pointed out, transpiration is several times faster during the day than during the night while absorption is more nearly uniform. The balance of importance and interest is rather one which will result in a normal growth.

In nature a healthy plant will maintain a balanced root and shoot for the average conditions of the habitat. This results in a steady growth of plant and a large number of seeds for reproduction, but often they are smaller in size than desirable for edible varieties. Natural plant growth requires a top of such size that an abundance of food can be made for seed formation, in order that the species may reproduce itself. In gardening, however, there are many cases where we get a more desirable result with a disturbed balance. We may prefer soft tender shoots of many of our vegetables, or fewer but larger flowers or fruit, which can be had

by reducing the top. The root must furnish the required water and mineral salts, including some form of nitrogen. Man has found that by increasing the relative root absorption by reducing the top he can grow, for the public, many improved plants. Most of our cultivated plants have been so modified by man's "improvement" that they could not survive in the wild state. An experiment of this kind to test the ability of wheat to reseed itself, showed a decrease each year for three years, but none appeared the fourth year.

Growth of flowers and fruits with their seeds consumes food instead of supplying it as do the leaves. For this reason plants usually flower after they have stored food, and many perennial plants fail to produce annual crops of flowers because the reserve of stored food is too low. Apples often bear fruit only on alternate years but continue to store food each year. Only a few plants (tomato is a good example) bear flowers or grow fruit simultaneously and consume food with extensive stem or root growth.

The condition of the balance of root and shoot can be determined best by the character of growth, which depends largely on the nitrogen supply, or more definitely the ratio of the nitrogen supply to the carbohydrate content. Because of their functions the problem of the balance of root and shoot and that of carbohydrate and nitrogen ratio may be identical; however the nitrogen supply to the plant may be increased by fertilizer applications. When the nitrogen content of the plant is high and the carbohydrates are available, proteins are made, at the expense of the storage of the carbohydrates, resulting in growth instead of food storage in stems, tubers, or fruits. If the nitrogen content is kept high, growth may go on at such an abnormal rate—using so much of the food—that the plant fails to get a storage supply sufficient to cause it to become reproductive, even to form flower buds. Growth with high nitrogen supply results in larger, dark green leaves, longer, thicker internodes, higher water content

of the tissues (due to lack of stored food), and smaller root growth.

Kraus and Kraybill in 1918 used tomato plants in a study of the carbohydrate to nitrogen ratio. Although their clearly described results greatly clarified this problem, which has received much attention, there are still some unexplained angles. They divided the carbohydrate to nitrogen ratio in a way so that four conditions or results were obtained with the plants: (1) A very high carbohydrate to nitrogen ratio, where nitrogen, being very greatly limited, probably limits growth with a resultant weakly vegetative plant condition. (2) A high carbohydrate to nitrogen ratio, where nitrogen is available but carbohydrates are in excess and occur in storage form, results in heavy fruiting. (3) A low carbohydrate to nitrogen ratio in which both are abundant but no carbohydrate is in excess for storage, results in high vegetative growth. (4) A very low carbohydrate to nitrogen ratio, in which the plant appears to be starved for carbohydrate, results in weakly vegetative growth.

The balance of root and shoot or the ratio of carbohydrate to nitrogen may be varied in any one of a number of ways. Pruning of the root or shoot is commonly practiced. Removing some of the shoot reduces the leaf surface and the carbohydrate supply from photosynthesis, which tends to lower the ratio if the nitrogen supply remains the same and for the healthy plant should result in number three condition. This is essentially the result obtained by pruning roses as is indicated by the size of new growth compared with a rose that is not pruned, but pruning must not be so severe that the number of flowers is reduced below a desirable set. Heavy applications of nitrogen may get the balance so abnormal that few flowers are produced because so little carbohydrate food is stored.

Root pruning will result in a decrease in the root absorbing surface and the supply of nitrogen. This tends to in-

crease the carbohydrate ratio and leads to the condition of number two. With no pruning the plant may reach this same condition, that is, a natural balance.

If the entire top of a plant is removed as is done in cutting weeds or brush, or in topping a tree we get different results depending on the time of year and the amount of food stored. Since most of these plants make rapid growth in the spring they use much of the food stored the previous season, after which storage takes place during the remainder of the summer. If plants are cut when the food supply is low in late July or August, the remaining food may be used and little will be stored for the next year. Under such a condition, the spring growth would resemble that for condition number four. But if the cutting is done in late fall or early winter the storage of food and undisturbed root system will bring about condition number three. Thus we can see the starved condition explains the physiological reason for the old adage "cut brush and weeds in August to kill them."

Transplanting unbalances the root and shoot by the loss of much of the plant's absorbing surface, so that transplants make little growth for some time. The slight growth of transplants, often called a time of "adjustment," may in many cases be due to low nitrogen resulting in condition number one. The removal of a part of the shoot is usually suggested in order to balance the plant for its water problem. It would be better to strive to save more of the root hair region, water the soil, restrict transpiration by shading and apply a little nitrogen to the soil. This will shorten the time necessary for the "adjustment" of the transplant, often causing earlier fruiting if a quick acting nitrogen is used.

In some plants such as lettuce or the lawn grass we may want more vegetative growth, as results with condition number three. It should be remembered that unless a quick acting, highly soluble nitrogen is used there is danger of keeping the shoot growing at the expense of the root, causing

a poor root system which would be detrimental to a lawn and most other perennial plants (Plate XIII). A moderate increase in the soil moisture is necessary for excessive vegetative growth.

Most plants may be given a quicker start in the spring by applying nitrogen to get a number three balance. The larger plant produced in this way results in more photosynthesis which tends to increase the carbon to nitrogen ratio in mid-summer and fall and to develop a well-hardened plant with a food reserve. This is the best kind of balance for most plants.

When sun-loving plants are planted in the shade photosynthesis will be retarded and they will tend to have high nitrogen and, depending on the density of the shade, will respond as in number three, or number four if in dense shade.

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Chapter Fifteen

INSECTS AND DISEASES

Every plant has its disease and insect enemies. In fact so numerous are these pests that amateur gardeners give up the struggle because of the study, effort, and expense involved in their control. The gardener's despair is understandable in view of the suggestion of the eminent plant pathologist, Dr. Smith, that "Plants may be found to have as many kinds of diseases as the human race." Dr. L. O. Howard, an entomologist of note, is even more gloomy in saying that by destroying man's food supply "Insects might destroy man." The annual loss of plants from diseases and insect pests can only be estimated but it reaches into billions of bushels of foods. The money loss from insects alone is estimated at more than three billion dollars. To the actual money loss because of the damage of pests must be added the cost of efforts toward the restriction of such damage, for example, 180,000 tons of poisonous bait was used in 1938 to control grasshoppers in the United States.

Successful control of insects and diseases depends on prevention rather than cure. A covering of poison spray on leaves not only protects the leaves from damage by killing destructive insects by the thousand but also prevents their reproduction. As is the case among humans, insects often act as agents to spread diseases among plants.

It is even more important to prevent plant diseases because when the insects are destroyed the plant they have injured may recover, but when a plant disease enters the plant it spreads rapidly, feeding on the protoplasm and soluble foods of the plant, and cannot be touched with a spray solution. Since it is almost impossible to kill a disease in

a plant, it is important to keep all of the leaves covered with a protective spray and so kill all of the organisms before they enter the plant. It is usually best to destroy a diseased plant. Although we have very little evidence to indicate that a "sick plant can be treated as we treat an infected animal" recent work on the control of the red spider in greenhouses suggests a possible approach to the problem. Since plants containing the poisonous selenium were found to repel red spider very small quantities of selenium as sodium selenate are now being successfully applied as a fertilizer for greenhouse plants.

There are several aspects of this problem encouraging to the gardener. (1) The epidermis of the leaves protects the plants against attacks of insects and diseases. (2) Many sprays are available which, if applied properly, will give almost complete protection. (3) Many of the sprays stimulate growth sufficiently to pay for the cost of spraying by increased yields even though no disease control was necessary. (4) Spray combinations may be used to give control of all the insects and diseases in the same solution. (5) Plant breeders have been able to produce varieties or strains which are less susceptible, as described in the chapters on plant breeding.

The unpalatable, tough epidermis with its cutin or hairy covering protects many leaves, as may be seen by comparing such leaves with those which insects select in a garden. In many cases the time of the opening of the stomata may be important in restricting the entrance of the germ tube from a spore, because if a germ is in dry air for a short time during its development before entering a stoma it is killed. In other cases the fungus can penetrate the epidermis with difficulty.

Most of the diseases are spread by spores, carried by the wind or by insects. They are so numerous in regions where plants have been growing that it is impossible to grow plants on which spores do not fall. When moist, spores begin to

grow by sending out germ tubes. These tubes enter the leaf—some through open stomata only, others by penetrating the epidermis. If the leaves are covered with a spray containing a compound poisonous to the germinating spore, it will be killed before entering the leaf. The spores germinate when the leaf has a moist surface from which the poison can enter the thin-walled tube of the spore. The importance of complete coverage of the leaf is evident when the stomatal

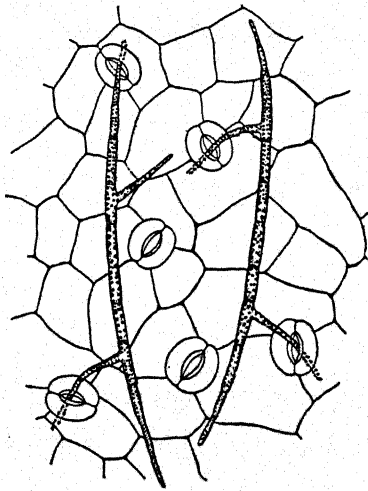


FIG. 16. Stomatal penetration of a sugar-beet leaf by the hyphae of *Cercospora beticola* Sacc. (From Melhus and Kent's Elements of Plant Pathology. By permission of The Macmillan Co., publishers, 1939.)

distribution is considered. Reference to the table on page seventy-five shows that because of the stomatal distribution of thousands per square inch and, for most plants in the garden, on both surfaces, it is very important to cover all the leaves completely on both surfaces with a material that will spread over every cell. It is necessary to spray frequently as long as new leaves continue to develop, in order to protect the whole plant from the entrance of diseases (Fig. 16).

The damage caused by animal parasites that chew and eat the leaves is more obvious than that caused by such

organisms as aphids that suck the plant juices. Since diseases are caused by microscopic organisms, often inside the host plant, it is impossible to see the early stages of injury and difficult to make a close association of the injury and the organism causing it.

The injury may be caused by the fungus growth, called haustoria, which may enter into the cell or grow between the

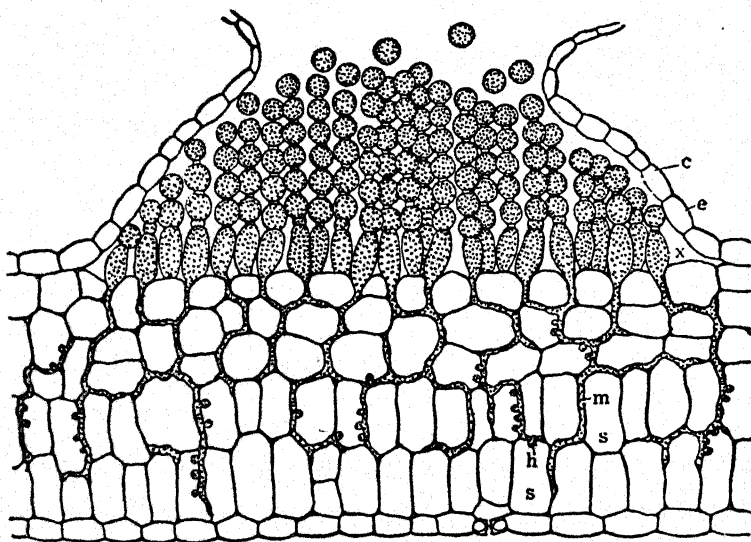


FIG. 17. Cross section of a radish leaf infected with *Albugo candida*. The intercellular mycelium, m, produces the haustoria, h, in the mesophyll cells, s. The conidia, c, are reproduced in chains from the conidiophores, x, and escape after the rupturing of the epidermis, e. (From Melhus and Kent's Elements of Plant Pathology. By permission of The Macmillan Co., publishers, 1939.)

cells. The infection of the radish leaf (Fig. 17) shows both types. In some cases the fungus secretes enzymes to digest plant material, and in other cases it absorbs material already in solution. After the fungus has penetrated a large area of the host tissue and can absorb large quantities of food it forms great masses of spores. In the above figure they are borne in chains but many other arrangements are known for other diseases. A single spore from such a mass can cause another plant to become infected. A new generation of

spores may be produced by some of the diseases as frequently as every ten days.

Neither the details of spraying nor lists of diseases and insects can be described in this book, but the reader will find the information in books and bulletins on the subject. Insects may be divided into two general groups, those that chew or eat the leaves, and those that suck the juices from the plant. The first group can be killed by spraying the leaves with a stomach poison, such as the various compounds of arsenic, including Paris green, compounds of lead, hellebore powder, and pyrethrum. The last two are gaining in popularity because they are less dangerous for animals. The sucking insects must be killed by spraying the material on them in order that it will enter their respiratory system. Since they are killed only by such contact sprays it is necessary to spray every portion of the plant bearing insects. It is frequently wise to spray two or three times a week if the infection is serious. Tobacco decoction (Black Leaf Forty), or kerosene with a soap emulsion is useful for aphids and plant lice. In addition to being an excellent contact spray, rotenone is very effective as a repellent to many insects. Early experimental reports indicate that when released from war duty a new chemical dichloro-diphenyl-trichloro-ethane called DDT will be the best all around insecticide. It not only acts both as a stomach and a contact poison but retains its effectiveness over a long period. Warning! It kills bees. Lime sulphur is usually used as a dormant spray for scale insects.

Diseases caused by bacteria or fungi are controlled in two ways. First, destroy all diseased plant material whenever it is found and especially in the late fall, to avoid keeping the disease from one season to another. Second, spray regularly with a fungicide in order to keep the new leaves covered with a spray material. Spraying once each week is usually enough. This protects the plants against the spread of dis-

ease in your yard or from your neighbors' yards. Copper and sulphur compounds are very effective poisons for most disease-producing organisms. Bordeaux mixture¹ is very widely used, but must be mixed at each application for best results.

Much time and effort is saved by mixing a stomach poison, a contact poison, and a fungicide together and using each time, because it will usually keep all the pests under control. The first insects and the first spores will be killed, preventing their reproduction.

Spraying may be considered a cultural treatment as well as a protection from insects and diseases. Tests made repeatedly with potatoes showed an increase in yield that more than paid for the spraying when the unsprayed plants had neither insect injury nor disease. A stimulation will be shown on many plants if they are sprayed and compared with unsprayed ones. Spraying is not a fertilizer, but it is believed to influence photosynthesis and decrease transpiration.

In order that effective work may be done spraying should be made as simple as possible. The leaf is more effectively covered as the spray becomes a finer mist; this is controlled chiefly by increasing the pressure. The larger power sprayers often use pressures as high as four hundred pounds per square inch, but with hand sprayers such pressures are impossible. However, if a sprayer is selected according to the number of plants to be sprayed more time can be used per plant with a smaller sprayer. The lower leaf is difficult to cover with the spray but it is the part that is most susceptible to infection because it retains moisture and because many species have more stomata on this surface. Therefore, the sprayer must have provision for effectively throwing the spray upward.

¹ Bordeaux mixture is usually used as a "5-5-50" mixture. Five pounds of copper sulphate should be dissolved in water and diluted to 25 gallons, and five pounds burned (unslaked) lime should be slaked to make a creamy mass, after which it should be diluted to 25 gallons. The two should be mixed and used fresh. If it stands some settling will occur.

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Chapter Sixteen

WEEDS

Weeds are plants of any kind growing where they are undesirable. Lawn grass in a tennis court, morning glories in the lawn, or petunias with the roses are weeds, even though each may be highly desirable in the proper place. Weeds are undesirable for many reasons: they give the place a neglected appearance, they compete with the desirable plants for light, they may actually crowd other plants, as the rosette weeds in the lawn, their root systems compete with other plants for water and mineral nutrients. "Good" weeds must have efficient methods of reproduction, either vegetative or seeds or both, and they must have such remarkable vigor that they frequently grow much faster than the cultivated plants, which favors them in their competition with the desired plants.

All plants, including weeds, may be divided according to the length of time they live and produce seeds, into annuals, biennials, or perennials. Annuals, such as crab grass, grow from seed and produce seed the same summer, after which they die. Winter annuals, such as shepherd's purse, grow a rosette of leaves and often a fleshy tap root late in the summer, rest over the winter, and send up a stalk bearing seeds the next spring, after which they die. Biennials start from seed in the spring and grow a rosette of leaves and a fleshy tap root. The next spring the stored food of the root aids in producing the flowering stalk which bears seeds and dies later in the same summer. Figure 18 shows the growth we normally see the first summer, as well as the type of growth made the following season. Most biennials grow a large flowering shoot the second season.

In most of the species of annuals and biennials the only method of reproduction is by seeds which are dormant until the next spring. Winter annuals bear seed in the spring which is dormant until late summer. Perennial weeds may



FIG. 18. Stages in development of the wild carrot, a biennial plant. The seedling (left), at the end of first growing season (center), a mature blooming specimen in second year (right). (From Maximov's Plant Physiology, after Transeau, McGraw-Hill Book Co., 1938.)

flower and produce seeds the first summer but usually only after one or more years of growth, when they may produce seeds each year for several years. In many cases, such as dock, the top dies each winter while the root remains alive. Many perennial weeds reproduce most effectively by vegeta-

tive methods. Most garden weeds are annual but the weeds in the lawn are of all three classes.

Weed seeds have well-fixed rest periods which have

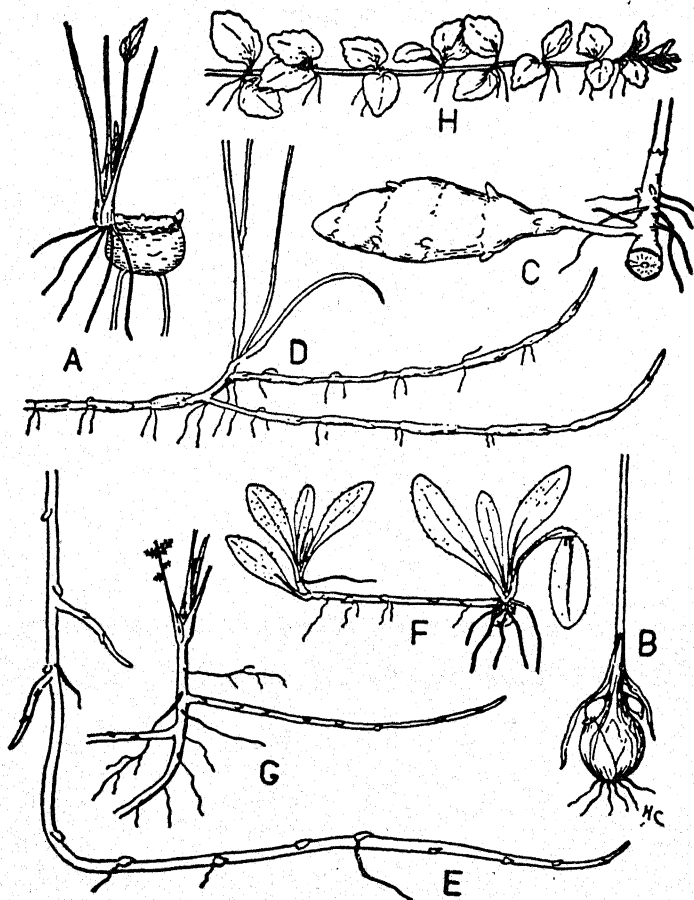


FIG. 19. Vegetative propagation of weeds by modified stems. A, *Ranunculus bulbosus*, corm. B, *Allium vineale*, bulb. C, *Helianthus tuberosus*, tuber. D, *Agropyron repens*, rhizome. E, *Convolvulus sepium*, rhizome. F, *Hieracium pratense*, stolon. G, *Achillea Millefolium*, rhizome. H, *Veronica serpyllifolia*, creeping stem. Reduced to about 1/3 natural size. (From Muenscher's Weeds. By permission of The Macmillan Co., publishers, 1936.)

enabled them to persist in various habitats. Many of them will remain in the soil for several years, after which they will germinate. Table II in the book on "Weeds" by Muenscher

gives some idea of the viability of weeds and the vast numbers of seeds and species found in random samples of soil. Lists of annual, biennial, and perennial weeds are given as well as detailed descriptions of many species with a recommended method of control. Many state experiment stations publish valuable bulletins on the identification and control of the common weeds of the state.

Weeds are propagated chiefly by seeds, but many of them have vegetative methods of propagation. Many weeds produce more than a hundred thousand seeds on a single plant, which helps to answer the question, why so many weeds. The seeds from a single plant may be widely scattered by one or more of the common methods of dissemination. The home gardener is most likely to get weed seeds from other places by manure, by wind, by impurities with seeds, or by animals (birds' excrement, or carried on the fur of cats or dogs).

Vegetative methods of weed reproduction most common in perennials are mainly: by buds from underground roots, or horizontal stems growing underground or close to the ground and rooting at frequent intervals. Muenscher shows some of the common weeds (Fig. 19) with buds growing from a modified form of stem. Each bud may grow roots and a new plant. The hawkweed, speedwell, and yarrow send creeping stems along the surface of the ground to root and grow new plants. Crabgrass grows horizontal stems above the ground and morning glories have underground stems with numerous nodes from each of which a group of roots and a new shoot may grow. Hoeing may cut these root-stalks into several sections, which if not removed will each produce a new plant. The creeping plants are usually so close to the soil that the lawn mower will not cut the stem but may remove some of the leaves.

Weeds can and should be controlled. In most cases it requires less time and effort, year after year to control them,

than is given to fighting them when they are allowed to grow rampant until they are mature, have damaged other plants, and have produced a crop of seeds for a new generation.

There are many methods of controlling weeds, but in each case it is easiest if we take advantage of a knowledge of the weed's life history. Weeds that grow from seeds in the cultivated areas can be destroyed very easily and rapidly by hoeing or raking when they are small seedlings. They have a small root system and have not commenced to store food. Most of them will die before the roots can become re-established to absorb water. Hand pulling of annual weeds is rapid and useful in small areas, but pull them while they are small; when they are grown they have done their damage and produced seeds for next year. Mature weeds take twice the time, ten times the effort, and have a hundred times as much material to destroy as young ones.

Some of the weeds with root-stalks are most difficult to eradicate. The plants may be entirely removed from a small area or they may be starved by keeping the new growth chopped off, or by using some other plant to smother them out. Weed manuals give detailed advice for various species.

Weeds in the lawn are more difficult to control than those in the cultivated area. They are not easily seen as small seedlings, and pulling after they have grown larger often destroys several plants of grass. The weed control should begin with the starting of the lawn. It is impossible to start the lawn without weeds but many can be avoided with thought. Sod may have undesirable grasses as well as many other weeds, but it is possible to get reasonably good sod.

Seed should be reasonably free from weed seed, but it is impossible to buy seed that is weed free. It should be free of the weeds that are considered to be the worst and are therefore unlawful.

A good lawn is the greatest help in fighting weeds, therefore, we should begin with the soil when we start the lawn.

The pH or acidity of the soil should be determined in the spring, and if it is more acid than a pH of 6, ground limestone should be mixed with the top 8 inches, or if possible the top foot, at the rate of 50 pounds per 1,000 square feet, or more if the soil is very acid. An application, 50 pounds per 1,000 square feet, of phosphate in the form of bonemeal may be mixed with the soil at the same time. The remainder of the summer the area may be kept free of weeds. About August first manure or other humus-bearing material should be spaded into the soil so that it has a six inch covering. (Most of its weed seeds will exhaust their food supply before they can reach the surface.) The manure is valuable at this time because humus is difficult to add later and the stimulation it gives the grass helps to control the weeds.

In late summer or early fall apply 30 pounds per 1,000 square feet of complete fertilizer and one week later sow the seed. The photograph (Plate VI) shows the influence of fertilizer on new grass. See Chapters 21, 22, and 23 for further information about soil improvement and the application of fertilizers. Daily watering with a very gentle sprinkle will be necessary unless rains are favorable, until the grass is well started. Not all species of grass germinate at the same time, for example, Kentucky bluegrass may require two weeks or more. If it gets a top of two inches or more it will need no winter attention.

The grass should make an early rapid growth in the spring. It should be cut frequently to a length of one and a half inches. If it is thick and standing nearly two inches high weeds will be shaded and weakened in their early seedling stages when they should be pulled to prevent their going to seed. Many of them will not have enough food stored in the seed to feed the seedling until it can carry on photosynthesis. Most annual weeds soon disappear under such conditions.

Crabgrass, the worst annual weed in the lawn, makes

such a good lawn in many regions during August and September when bluegrass lawns are least vigorous that many people make the mistake of not considering it a bad weed. It is objectionable and a serious weed because it injures the better grasses so seriously that a poor lawn usually results for the other ten months.

The eradication should begin by providing an unfavorable environment for its growth in June and early July when it germinates. If the grass has been kept growing well by watering heavily at weekly intervals when necessary, it will have a dense top and a deep root system, so that the crabgrass roots will find low nitrogen and moisture in the surface soil and the shoots will be crowded and shaded by the established grass. The crabgrass plants will have roots beginning an inch above the soil level and the leaves will be upright instead of growing prostrate as they do on a thin lawn. They grow slowly under these conditions and can be pulled surprisingly easily or cut close to the roots when mowing. This is the easiest time to fight crabgrass where the infection is mild, in fact, when the plants are fully grown, pulling is too difficult.

Nothing favors crabgrass in the lawn more than summer application of fertilizer and sprinkling lightly every day. The deep rooted grass suffers for water and grows slowly while the new crabgrass seedlings can grow with less competition and have water for their shallow root systems. If the lawn becomes too badly infested to control in July and August, it should be mowed and raked out with an iron rake in the fall and seeded under more favorable conditions, with the ambition to have it in control next summer. Some of the chemical treatments for crabgrass make its eradication easier than to rake out the growing plants.

Biennial and perennial weeds, such as plantain and dandelion, may persist, but will spread very little. Here again fertilizers, if applied in late fall or very early spring,

will improve the thickness of the turf and retard the growth of weeds, as shown above. Those remaining may be pulled, but some of the newer chemical treatments may be more rapid. A number are in use for spraying, but for scattered weeds in a lawn the spot method is best. A small amount of a chemical is put on the center of the crown or on the cut surface of the tap root of the weed, to destroy the growing point and the conducting system to the older leaves. Ammonium sulphate may be used by dropping a small amount of the powder on the center of the weed. It acts also as a fertilizer to stimulate the grass, making it spotty. Gasoline, carbolic acid, dilute sulphuric acid, or cleaning solution may be used if applied from a small grease can. Only a few drops are needed on each plant, a method surprisingly rapid which does little damage to the grass. The plants will die in one or two days.

Weeds may be destroyed in paths, tennis courts, and other open areas by spraying with sodium chlorate at the rate of about $\frac{3}{4}$ pound per gallon of water. This will kill other plants and will prevent plant growth for about a year. Poison ivy may be killed by two or three sprays of this solution at weekly or ten-day intervals.

Heavy weed infestations may be killed by spraying even on a lawn with iron sulphate or sodium arsenite, but several applications will be necessary and the tops of the grass may be burned with each spraying. For details of these methods Muenscher's book "Weeds," which explains the use of several chemicals, should be consulted.

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Chapter Seventeen

FLOWERS

A flower is a stem with variously modified leaves, crowded on a short axis, which leads to sexual reproduction of the species through the formation of seeds. Each part of the flower (petal, stamen, etc.) is a modified leaf lacking the bud at the axil which is common to leaves. The flower usually stops the growth in length of that particular stem or branch by destroying the terminal meristem.

Flowers are harbingers of seeds but the plant lover sees them as the culmination of a great chain of events in the life of the plant. When all the conditions for a particular seed-bearing plant are favorable it will bear flowers. Many plants, it is true, have flowers so inconspicuous that they are seldom noticed and never valued for their flowers. Grasses, oaks, pigweeds, and many of the chickweeds go unnoticed because their color or size fail to attract us. Plants may grow in a locality for many years without flowering if some condition is unfavorable, but most plants when fully adapted to their surroundings will develop internally in such a way that flower buds and flowers will appear. After many years of study much of the real nature of the *length of day* influence, described in Chapter 12 and the *carbon-nitrogen ratio* to be explained in Chapter 23, remains a secret, but enough is known to enable man to regulate at will the flowering period of many of our cultivated plants.

Some plants, such as the tulip, bear their flowers singly on the end of a stalk called a peduncle; others, such as the petunia, bear theirs singly at the axils of ordinary leaves. Most plants, however, bear their flowers in a cluster or group called the inflorescence. Most flowers grow like the larkspur

or snapdragon in some type of racemose inflorescence, with the lowest flower buds opening first, while the central axis continues to grow in length, forming new flower buds. The flowers may be sessile, that is they may grow directly from the stem or spike, as does the gladiolus, when they are called spikes or they may grow on short stems or pedicels, as in

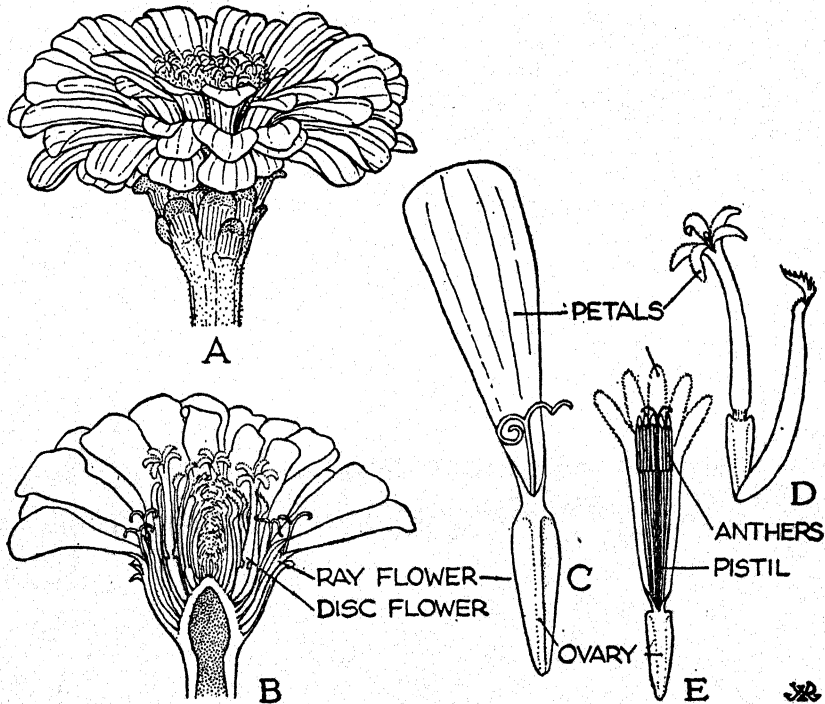


FIG. 20. *Zinnia*. A, general view. B, section to show the position of the two kinds of flowers. C, a ray flower. D, a disc flower with a bract. E, a disc flower split to show the united stamens and the two-part stigma. A and B, natural size. C, D and E, 2 \times .

hibiscus, when they are called racemes. A bloom with outer flowers on longer pedicels than the younger ones and the main axis a little elongated so that the top is flattened as it is in cherry blossoms is called a corymb. In the wild carrot flower the main axis is an umbel. The head is an inflorescence with a very short axis and sessile flowers as in the

zinnia (Fig. 20, A and B). Inflorescences with branches from the main axis and a loose flower cluster such as the larkspur are called panicles.

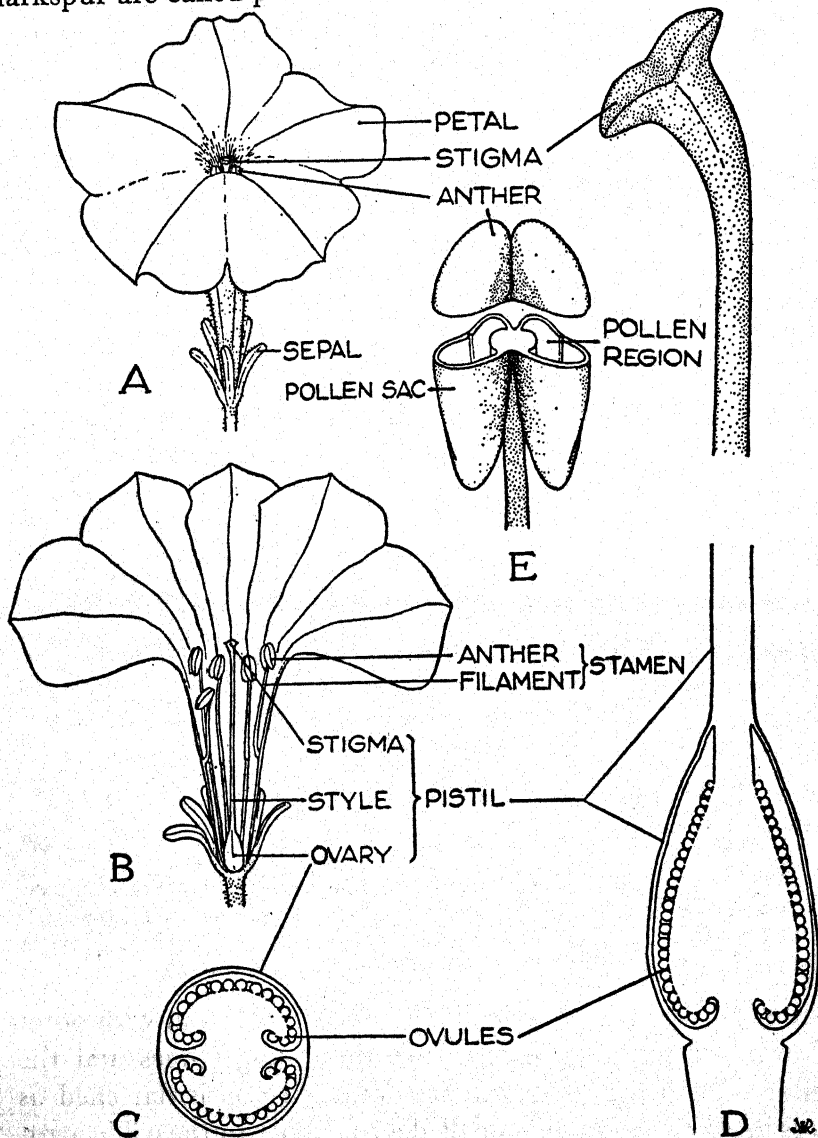


FIG. 21. *Petunia*. A, general view. B, split to show the relation of the flower parts. C, cross section of the ovary with the ovules. D, longitudinal section of the lower part of the pistil and a side view of the upper part. E, anther with cross sections to show the pollen cavity. A and B, natural size. C, D, and E, $9\times$.

The complete flower consists of four types of parts. Further study of flower development, seed formation and plant breeding require a familiarity with these parts. The most fascinating way to become acquainted with flower structure is to collect several kinds to examine and compare their various parts. Several illustrations will be helpful in the terminology.

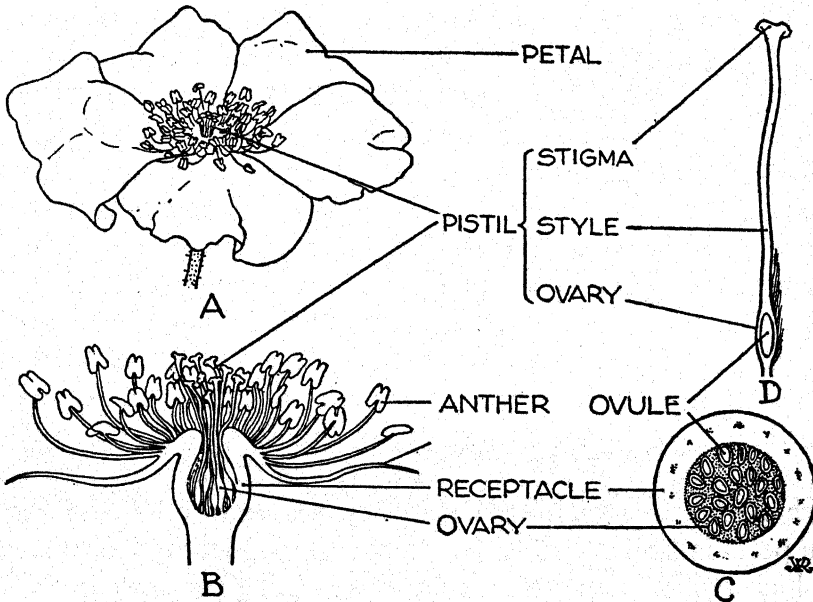


FIG. 22. Rose. A, general view of a single rose. B, section to show the relation of stamens and pistils. C, cross section of the receptacle to show the ovaries. D, a single pistil. A, natural size. B, 2 \times . C and D, 4 \times .

The sepals make up the calyx, which is the outer and lower whorl of flower parts (Figs. 21 and 22). These are usually small green leaf-like structures, which in herbaceous plants often enclose and protect the more delicate inner part of the bud. In a few flowers such as the tulip they are similar to the petals in color and shape. The calyx may fall off when the petals fall or it may remain, as it does at the base of a pea pod, on the apple opposite the stem, and around the capsule of petunia.

The petals, which make the corolla or the showy part of most flowers, are either united, as in petunia (Fig. 21, A) and the zinnia (Fig. 20, B, C, D, and E), or separate as in the rose (Fig. 22, A). Such flowers as the sweet pea and snapdragon are called irregular flowers because of the irregularity in the shape of their petals. The nectar glands are usually attached at the base of the petals. Flower colors and odors are known, at least in some cases, to attract insects.

The stamens, inside the petals, vary in number in accordance with the kind of flower. Some flowers have fewer stamens than petals, some have the same number, and some have many more (Figs. 20, E; 20, B; and 22, A and B). The enlarged top of the stamen is the anther, which bears the pollen (Fig. 21, E) from which the male sex-cells develop. The anthers may open to shed the pollen before the stigma is "ripe," at the same time, or after, depending on the habit of the plant. When the pollen and stigma are "ripe" at the same time pollination is likely to take place between them, but early- or late-maturing pollen favors cross-pollination. The stamens are attached to the base of the flower through which they get food, but often they adhere to the corolla as in petunia (Fig. 21, B). In a few flowers, such as the zinnia (Fig. 20, E), they form a tube surrounding the style.

The pistil is in the center of the flower. In the sedums there are five pistils; the rose has several separate one-seeded pistils in an urn-like receptacle (Fig. 22, B and C), but in iris there is a single pistil of three united modified leaves (called carpels) as is shown in Figure 3, B, by the three cavities for seeds. The petunia has two united carpels as shown by the division in ovary (Fig. 21, C) and the divided stigma in D. The top of the pistil is the stigma on which pollen must fall in pollination. It usually has a finely irregular surface or fine hairy covering which catches the pollen and which contains a substance that stimulates its germination. The style is a solid structure connecting the stigma with the base of

the pistil, called the ovary, which contains the one to many ovules (Fig. 21, C and D) in each of which a single egg cell develops. The pollen tubes must grow through the style, which may be quite long as is the corn silk which extends to the kernel. At least one pollen tube must grow through the style into the ovary to enter the micropyle of each ovule and discharge a pair of sperms for fertilization. Careful studies of the petunia were made in which it was learned by counting the seeds of several mature ovaries that each ovary contains at least five hundred seeds (Fig. 21, C and D). Since each of these seeds requires a pollen tube, the slim style (Fig. 21, D) about the size of a large pin, must contain at least five hundred pollen tubes. Other workers have found that usually more than twice as many pollen grains begin to grow pollen tubes as are needed to fertilize all the ovules. Although the diameter of the petunia stigma as shown in Figure 21, D, is about one-tenth of an inch, it is large enough to hold a thousand pollen grains, each of which is only about one-sixth of one-hundredth of an inch in diameter. A single layer over the entire stigma would require more than two thousand pollen grains. They are so small that only masses are visible and for that reason the cavity of the anther is shown in Figure 21, E, without pollen.

Flowers differ in many respects; in fact, they are so different that most plants can be identified by their flowers. Their differences may be marked, and constitute a group, as the following three which will be described in some detail: the sweet-pea or clover type, the sunflower type, and the grass type.

The sweet-pea type has two petals forming a keel over the stamens and pistil, two wing-like petals, and a broad petal opposite the keel, called the standard. Nine of the stamens have the lower parts of their filaments united to form a tube around the pistil, the tenth one remains separate. The pistil has the stigma at one side instead of on the end, and the ovary with a single cavity containing several ovules.

Composite flowers, known as the sunflower type, such as the sunflower, zinnia (Fig. 20, A), and dandelion, grow in heads. Each part is a true flower with a small inconspicuous calyx of hairs, bristles, or bracts, called pappus. In the dandelion it becomes the group of hairs attached to the ripe seed. The corolla is of two kinds; as illustrated in the zinnia, each broad petal-like structure is a group of five united petals, called a ray flower (Fig. 20, B and C). The center has numerous flowers with the petals united to form small tubular disc flowers (Figs. 20, B, D, and E). D shows the bract common on many composite flowers. Dandelions have only ligulate flowers. The five stamens have their anthers united to form a tube around the style (Fig. 20, E, shows the flower opened to display the stamens and pistil). The pistil has a two-parted stigma and an ovary which bears a single seed. The seed remains in the ovary which is planted as a seed.

The grass flowers grow in groups called spikelets. They are so small that they are not recognized as being common to all our grasses including corn and other cereals. Each spikelet has a pair of scale-like parts called glumes, between which the one or more flowers are located. Each flower has a pair of scales which enclose the three stamens and the pistil. The pistil has a two-parted plumose stigma and an ovary with a single seed. A single corn kernel with its silk ending in the divided stigma is the pistil. At the base of the flower are two small bodies called lodicules which swell and push the pair of scales apart at the time of pollination. The flower structure is easily visible and delicately attractive when shedding pollen.

The pollen is borne in great abundance in the stamens, several millions of the cells or pollen grains being produced by a single plant. In a few plants, such as the orchids, it sticks in masses, but in most plants the individual grains form a powder or dust. Each pollen grain is a single cell with



PLATE VII. Mendel's garden and the monastery (as it appeared about 1915). (From Ilitis' Mendel Museum.)



PLATE VIII. Methods of applying colchicine. A—*Portulaca* plants showing method of treating stems by immersing their tips in solutions of colchicine. Such treatment has induced doubling of chromosomes. B—A successful method of inducing chromosome doubling by covering the tip of a *Datura* plant with an agar solution of colchicine. C—Capillary string method of treating buds with solutions of colchicine. One end of string is immersed in a bottle of solution and the other end is wrapped around buds to be treated. D—Method of applying spray of colchicine solutions by means of an atomizer with air pressure furnished by a spray tank. The air pressure valve manipulated with the left hand was obtained from a dental supply house. E—Drop method of treatment. On right a drop of solution is being applied to a seedling *Datura*. On left a

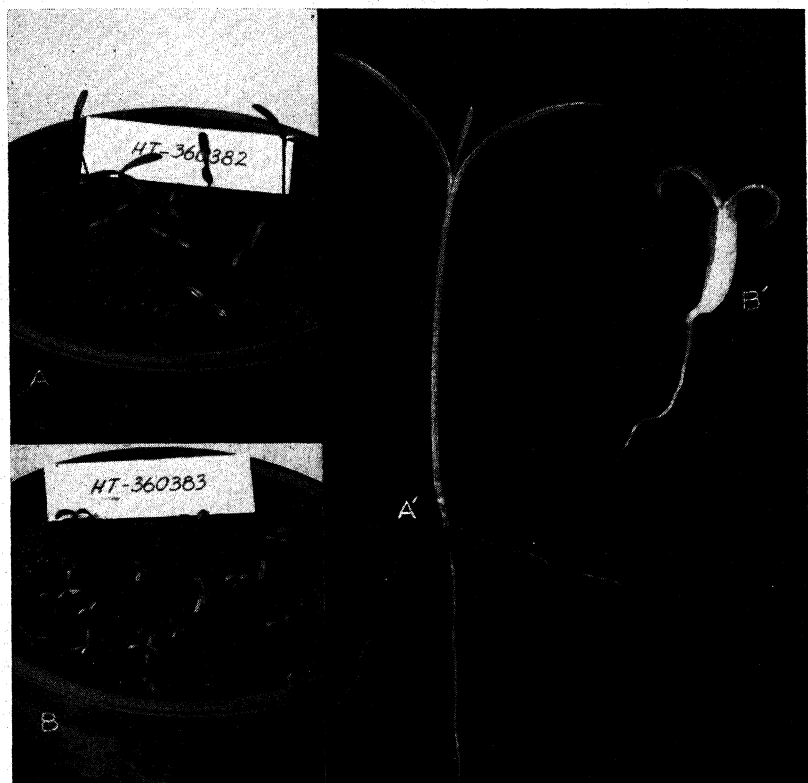


PLATE IX. Deformity resulting from colchicine treatment. Seedlings of *Cosmos* photographed about two weeks from planting. A-A' show seedlings of untreated controls; B-B' show seedlings from seeds treated for four days with 0.05 per cent colchicine. Seedlings from treated seeds have swollen stems and poor root development. In consequence, they are often washed out of the soil when the seed pan is watered because of lack of root anchorage. It is these dwarfed and malformed seedlings which produce the tetraploid tissue which in the next generation may give rise to pure-breeding polyploid species due to their containing both diploid and tetraploid tissue. (From Journal of Heredity, vol. 28, p. 397.)

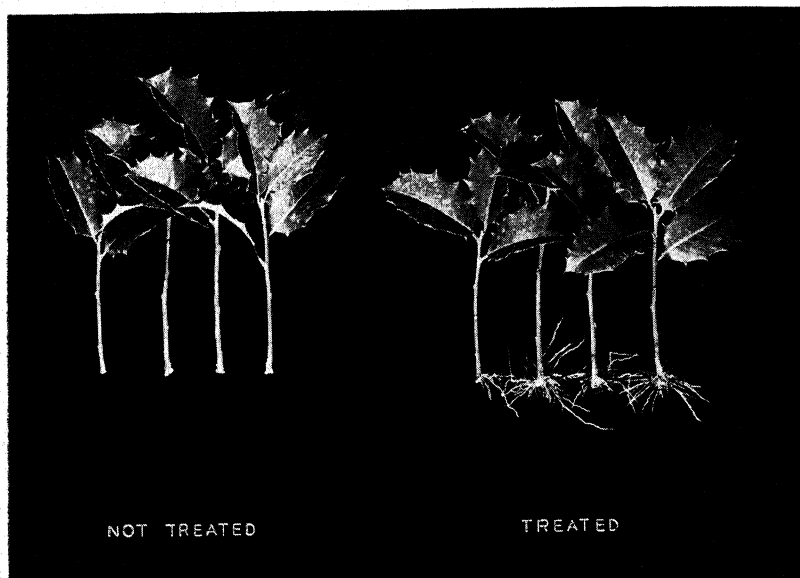


PLATE X. Rooting response after 39 days of *Ilex opaca* (holly) cuttings. *Left*, basal ends soaked in water. *Right*, treated for same time in indolebutyric acid.

a protective wall, which is so characteristic in structure that its species can often be determined. Bee-keepers can determine the plants supplying the honey flow by examining the pollen on the bees.

Pollination is the transfer of pollen from the anther to the stigma. Wind and insects are the chief agents of pollination, although some flowers have structures in which no outside agency is necessary. Cross-pollination refers to a transfer from the anthers of one to the stigma of another plant, while self-pollination includes all cases of transfer on the same plant.

The pollen grain germinates when it lights on the stigma and by the action of its enzymes grows a tube through the style into the ovule. During the development of the pollen tube the nucleus, which contains the chromatin, or the heredity carriers, divides and finally forms two male sex cells called sperms. These are released in the embryo sac in the region of the female sex cell or egg. It is important that the pollen tube grows well in the style. Studies have shown that in cross-pollination there are many cases of incompatible pollen, resulting in failure to grow properly in the style. The rate of growth in the styles has been studied by splitting them after pollination.

While the pollen grain is germinating the ovule in the ovary develops into a many-celled structure in the center of which are three important cells: the egg cell, and two polar cells or bodies. The egg cell has a nucleus which bears the chromatin of the female plant.

Fertilization results when a male sex cell fuses with a female sex cell. This fertilized egg cell is the beginning of the new plant called the embryo. It contains the heredity carriers or genes of both sex cells. The second male sex cell fuses with two polar bodies, and becomes the endosperm. This explains the origin of the embryo and endosperm of the corn kernel (Fig. 1). Fertilization results in a powerful

stimulus, not understood, which causes the fruit to grow. If fertilization takes place in ovules in only one side of an apple, the unfertilized side will get little stimulus and the apple will be poorly developed. If none of the ovules are fertilized the ovary soon falls from the plant. Recent investigators have been able to stimulate the growth of fruits like tomatoes by applying a chemical stimulator on the stigma. Such fruits are without seeds.

Xenia is the domination of the sperm over the polar bodies in the development of the endosperm. This is evident in the case of the pollination of sweet corn by field corn. The sperm from field corn dominates and determines the character of the endosperm causing it to be starchy like field corn instead of sweet like the character of the polar bodies. Sweet corn grown near field corn will have many starchy kernels on an ear, which will be very conspicuous when the corn is ripe because of the sunken sweet corn kernels. If field corn is pollinated by sweet corn pollen the sperm will not dominate field corn polar bodies, therefore the endosperm will be starchy. This also occurs where colored strains are crossed, resulting in ears with kernels colored like the male parent.

Metaxenia is a term coined by Dr. Swingle a few years ago to describe the influence of the pollen on the fruit. It should be remembered that the tissue of the fruit is from the female parent and therefore bears only genes of that parent, hence any influence of the pollen on the fruit tissue must be carried by a diffusible substance. This influence was first described about two hundred years ago, but has been studied by only a few people.

A number of crosses have been made with apples; in certain of these, very definite increase in size, sugar content, acidity, and keeping quality resulted from the pollen influence. In any work of this kind it is important to remember that the size of the fruit may depend to some extent on the number of developed seeds. Here again a stimulus passes

from the fertilized seed or some associated structure, to increase the size of the fruit.

Dr. Swingle found that certain pollen was very important in its influence on the quality and time of maturity of the fruit of the date. No one has found the substance or active principle responsible for these fruit variations, and its method of movement to the fruit is a mystery, but since we know there must be something, it is not too much to expect that we may some day influence the fruit by a chemical spray. Certainly a new interesting field is opened for improvement of all kinds of fruits.

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Chapter Eighteen

HYBRIDIZING PLANTS

The hybridizing of plants is a method of improving the beauty or economic value of plants. The object of hybridizing or crossing is to get certain selected desirable characteristics of two strains or varieties into a single individual. In certain cases a plant breeder may find a plant with a single characteristic which he wants to substitute for an undesirable character in an otherwise desirable plant. A common example of this kind of breeding is the effort to develop resistance to a certain disease common to a garden plant by crossing it with a wild plant which is worthless except for its characteristic resistance to this disease. For instance, rust resistance has been taken from a wild species of snapdragon and introduced into many varieties of cultivated snapdragon. Rust resistance found in Khapli Emmer wheat was introduced into common wheat. The tobacco mosaic virus disease is a serious disease not only of tobacco but of tomato and many other plants. In *Nicotiana tabacum*, the common Turkish tobacco, the disease spreads throughout the plant and becomes very severe. In *Nicotiana glutinosa*, a related wild species, the disease is localized in small spots or lesions. By crossing the two species, and then by backcrossing the progeny of this cross to the common tobacco many times, the character for local lesions was introduced into a number of commercial varieties of Turkish tobacco. Note that a character such as disease resistance from a wild plant can not only be introduced into a cultivated plant, but into a particular *variety* of the cultivated plant.

Hybridization of plants has become a very useful and fascinating science. Governments, the world over, have

realized the vast possibilities for the improvement of plants and have employed thousands of people in the work. "Hunger Fighters" by De Kruif gives a few examples of the results. Only a few examples are given in the next chapter, but gardeners have used the method to develop thousands of new plants. Common examples are the hundreds of varieties of roses, irises, tulips, peas, while the number of varieties of the staple grains such as wheat, barley, corn, sorghum, and rice can be counted in the tens of thousands.

It is impossible for most individuals to become acquainted with all of the vast amount of work that has been done, but before the actual work of hybridizing is begun, it is wise to get a knowledge of cell structure and the principles and laws which have been found to be fundamental. More failures than successes will result and the beginner must plan to do years of work if he hopes to attain the satisfaction of a plant breeder. But for the amateur there is no greater thrill than the creation of a new and distinctive variety. These new varieties can often be entered in competition in flower shows and recognition by the judges brings the satisfaction of real creative achievement.

In some respects plant breeding is as much an art as a science, but the inheritance of characters is based on certain principles and laws which must be understood by the plant breeder. The fundamental principles of development are: first, all organisms develop from a single cell by a long series of cell divisions; second, since these divisions separate the chromosomes equally all cells of the organism bear the same assortment of genes, and third, each gene can be considered as a minute portion of a chromosome located at a definite place in the chromosome and determining the expression of one or more characters of the organism in the course of development. The fundamental laws of inheritance were discovered by Gregor Johann Mendel and will be explained shortly.

The laws of inheritance, now called Mendelian laws, are

so important and Mendel's proof of them so clear and so carefully worked out that it would be well worth our while to examine Mendel's experiments in detail. Gregor Johann Mendel was an Austrian monk living at a monastery at Brünn (Plate VII) which has since become a Czechoslovakian and at present a German town. He did his work in the 1850's and 1860's publishing his results in 1866. He was slow, careful, analytical, and did not jump to conclusions. His success where others had failed lay entirely in his analytical procedure. Instead of considering all the differences between two varieties when he crossed them, he considered just one difference at a time. The plants he worked with were garden peas. He selected them because they are normally self-fertilized, are easy to cross, and he had a number of varieties which were easily distinguished from each other.

Mendel did not plunge immediately into haphazard crossing experiments. First he selected his material carefully. He obtained a number of varieties of peas from seed houses and grew them. Those varieties which were not uniform he discarded. He carefully selected varieties which differed from one another by characters which were easily recognizable. Finally, since he considered only one character at a time, he selected his varieties by pairs contrasting different expressions of the same character. For instance for the character, height, he selected two varieties and only two. One of the varieties was tall, the other dwarf. For the character, shape of seed, he selected two varieties, one with smooth seeds and one with wrinkled seeds. Thus, in all he selected seven pairs of varieties differing in seven different ways. His first seven experiments consisted of crossing the members of the seven pairs with each other.

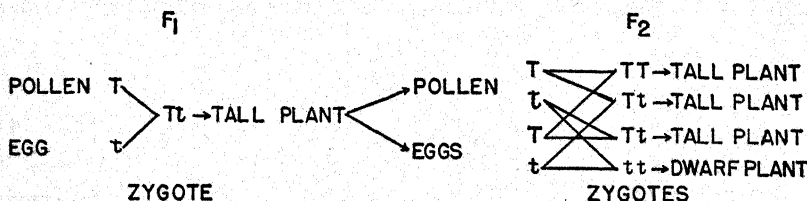
Mendel's first experiment was to cross a variety of tall peas (70-80 inches) with a variety of dwarf peas (8-18 inches). The progeny of the cross were all tall. It made no difference whether the tall variety was used as a male or female parent. The first generation resulting from the cross

(usually designated as F_1 , first filial generation) consisted of nothing but tall plants. These plants were permitted to be self-fertilized, and a second (F_2) generation was obtained. This generation consisted of some tall and some dwarf plants. Thus, Mendel showed that the dwarf character was not lost in the cross, but was transmitted from the parent to the second generation even though it was not expressed in the first generation. Since the tall character masks the dwarf character in the F_1 , it can be said to be *dominant* to dwarf. Conversely, dwarf is *recessive* to tall. The principle of dominance is of great importance in plant breeding, but all characters are not necessarily dominant or recessive.

Important as this discovery of dominance was, Mendel's analytical method led him to a still more important discovery. He not only observed that the second generation had both tall and dwarf plants, but he counted up *how many* of each. His F_2 generation consisted of 787 tall plants and 277 dwarf plants. This is a ratio of 2.84 to 1 or approximately 3 to 1. His second experiment, crossing a plant with smooth seeds with one with wrinkled seeds gave similar results. The F_1 consisted of plants all of which had smooth seeds. The F_2 consisted of 5,474 plants with smooth and 1,850 plants with wrinkled seeds or a ratio of 2.96 to 1. Again the approximation is 3 to 1. The results of the other experiments were similar. In each pair of characters, one was dominant in the F_1 , and the F_2 consisted of approximately 3 dominants to one recessive. The results of all seven experiments are shown in the following table:

<i>Nature of Character</i>	<i>Dominant</i>	<i>Recessive</i>	<i>Ratio</i>
Height of plant	787 tall	277 dwarf	2.84-1
Shape of seed	5474 smooth	1850 wrinkled	2.96-1
Color of flowers	705 colored	224 white	3.15-1
Color of cotyledons	6022 yellow	2001 green	3.01-1
Type of pod	882 inflated	299 constricted	2.95-1
Color of pod	428 green	152 yellow	2.82-1
Position of flower	651 axial	207 terminal	3.14-1
Total	14949	5010	2.98-1

Thus Mendel showed that even when thousands of plants were used, the F_2 had a ratio of approximately 3 dominant plants to one recessive plant. There must be some reason for this behavior which is consistent enough to be a basic law. Mendel did not know about genes, and the chromosomes hadn't been discovered. He did know that there were two sex cells necessary for fertilization. Since these sex cells unite to form a new individual, they must contain characteristics of their respective parents. Suppose we were to take pollen from a tall plant and put it on the stigma of a dwarf plant. The pollen contributes some element or factor for tallness; the egg contributes an element or factor for dwarfness. Since all of the F_1 were tall it is evident that when both factors are present the factor for tallness dominates the factor for dwarfness. But, dwarf plants appeared in the F_2 . This means that the factor for dwarfness must separate from the factor for tallness and appear by itself in a pollen cell or an egg cell. This can be represented diagrammatically as follows. Let T represent the factor for tallness and t the factor for dwarfness, then:



As soon as we conceive of the idea of the factor for tallness separating from the factor for dwarfness in the formation of pollen and egg cells, we see the reason for the 3 : 1 ratio in F_2 . Those plants with two elements for tallness are tall; those plants with one tall factor and one dwarf factor are tall, like the F_1 ; and only those with two recessive factors are dwarf.

Now, if this is the case, it should be possible to show, by selfing the F_2 plants, that some of the tall plants are pure and will breed true while some are like the F_1 and will produce some dwarf plants. This was perceived by Mendel, and

a further test of his theory was made. It was found in F_3 that about $1/3$ of the tall F_2 plants bred true and $2/3$ behaved like the F_1 plants, producing a $3:1$ ratio. All of the F_2 dwarf plants bred true. There is still another way by which the theory could be tested. If the F_1 were to be backcrossed to the parents, we would expect different results. If the F_1 were backcrossed to the tall parent ($Tt \times TT$), we would expect all the progeny to be tall since all of them would contain at least one T . But if the F_1 were backcrossed to the dwarf parent ($Tt \times tt$), we would expect one half of the progeny to be tall (Tt) and one half dwarf (tt). Again Mendel saw the possibility, and the final test of his theory was made. The results were exactly as expected. The backcross with the dwarf parent gave a ratio of 1 dominant to 1 recessive, while the backcross to the dominant parent yielded only dominant progeny. Thus, the first Mendelian law of inheritance was discovered before anyone had ever described a chromosome or heard of a gene. The law can be stated as follows: THE MEMBERS OF PAIRS OF ALTERNATE FACTORS OR ELEMENTS SEPARATE INTO SISTER GAMETES. This is known as the law of segregation or Mendel's first law.

Mendel did not stop here but proceeded methodically toward the development of his second law. The next step was to cross two strains which differed in two ways. Thus, his eighth experiment was to cross a variety of peas with round, yellow seeds with a variety having wrinkled, green seeds. As we might expect, the F_1 consisted of plants with round, yellow seeds, since round is dominant to wrinkled and yellow dominant to green. His results for the F_2 are as follows:

315 round yellow (parental combination)

101 wrinkled yellow (recombination)

108 round green (recombination)

32 wrinkled green (parental combination)

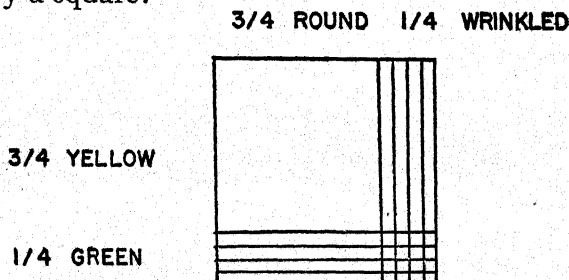
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The first point to note is that while the original parents were round yellow and wrinkled green, the F_2 has two new classes,

wrinkled yellow and round green. The original combination of characters is known as the *parental combination*. The new classes are known as the *recombinations*. The second point to note is that the first Mendelian law still operates. Notice that those plants with yellow seeds are $315 + 101$ or 416 while the plants with green seeds number $108 + 32$ or 140. This makes a ratio of 2.97 dominants to 1 recessive or approximately 3:1. Similarly for the other characters, there are $315 + 108 = 423$ round and $101 + 32 = 133$ wrinkled or a ratio of 3.26 to 1. This again approximates a 3:1 ratio. The ratio of the four classes together approaches 9:3:3:1. This means that the two 3:1 ratios mentioned above operate independently of each other. Mendel represented this condition by a simple algebraic multiplication:

$$(3A + a)(3A + a) = 9AA + 3aA + 3Aa + aa$$

This may be simple algebra, but what does it mean? It means simply this: by Mendel's first law we would expect to get in F_2 a ratio of three-fourths of the plants with round seeds and one-fourth of the plants with wrinkled seeds. Now when we take into account the other pair of characters we find that they operate independently. Thus, we expect the three-fourths of the plants which have round seeds to be divided into two classes, 3 yellow to 1 green. Similarly, we expect the one-fourth of the plants which have wrinkled seeds to be divided into two classes, 3 yellow to 1 green. This gives our four classes and the 9:3:3:1 ratio mentioned above. Diagrammatically, the F_2 population can be represented by a square:



If we compute the areas of the sections within the population square, we find:

$3/4 \times 3/4$	$9/16$	Round yellow
$3/4 \times 1/4$	$3/16$	Wrinkled yellow
$1/4 \times 3/4$	$3/16$	Round green
$1/4 \times 1/4$	$1/16$	Wrinkled green

Again, Mendel proceeded to test his theory carefully by carrying the experiment to the F_3 generation. He was able to show that all the wrinkled green F_2 plants bred true; all the wrinkled yellow plants bred true for wrinkled, but $2/3$ of them split up into a $3:1$ ratio for yellow. All the round green plants bred true for green, and $2/3$ of them had a $3:1$ ratio with respect to round. And finally the round yellow plants behaved variously; only one out of every nine bred true for round yellow; some gave $9:3:3:1$ ratios like the F_1 ; and others bred true for yellow, but not for round; and some bred true for round but not for yellow. He had evidence enough to propose a second law which has now become known as the law of independent assortment or the second law of Mendel. It can be stated as follows: THE MEMBERS OF DIFFERENT PAIRS OF FACTORS SEGREGATE INDEPENDENTLY IN GAMETE FORMATION.

This did not complete Mendel's work, but his later work is not of such fundamental importance. His work has since been repeated by many workers and found to be sound. For instance, the experiment of the yellow-seeded variety crossed with the green-seeded variety was repeated by a group of people, and the final results for the F_2 were 146,802 yellow and 48,675 green or a ratio of 3.016 to 1. We might note at this point that even with nearly 200,000 F_2 plants, the ratio is not *exactly* $3:1$. The larger the number of F_2 plants, the closer the ratio approaches $3:1$, but seldom does the ratio actually become exactly $3:1$. If you make a cross between varieties in a garden, which involves a single character difference, the chances of obtaining a perfect $3:1$ ratio in the F_2

are slight. If you made the cross a great many times, however, the average ratio would be close to 3 : 1. The reasons for the deviations are based on the laws of chance which we need not go into here. But anyone who has played bridge knows that the laws of chance are capricious to say the least. That is why precise ratios are not to be expected, but may occur even in a small number of plants by chance alone.

But, let us consider Mendel's work once more. It was a model in experimental research, and its importance as a milestone in the history of biology, science, and human philosophy can not be overemphasized. Without knowledge of chromosomes or genes Mendel worked out the basis for the inheritance of characters. The laws which he formulated have since been shown to hold for every organism, plant or animal, which reproduces sexually. It is surprising, then, that a paper of such fundamental importance to the entire scientific world as well as to the layman should have gone unnoticed at the time of its publication. The paper was read before the Natural Science Society of Brünn (Brno) in 1865 and published in the Transactions of that society in 1866. It received little comment and was filed away on the shelves to be forgotten. Mendel, realizing the importance of his discoveries, wrote to the outstanding European naturalist of the time, Carl Naegli, but the significance escaped even this scientist. Mendel died still believing in his work and its importance. It wasn't until a generation later, in 1900, that his paper was discovered again. Three men, DeVries of Holland, Correns of Germany, and Tschermak of Austria, each one independently of the others, discovered Mendel's paper, in the library at Brünn, stuffed back on a shelf where it had accumulated dust for 30 years. Each of the three scientists reported the finding of the paper and, although each had gotten similar results in his own work, they very properly gave Mendel the credit for his complete understanding of the whole problem.

Mendel's understanding of the problem of the inheritance of certain characters was genetically complete. But, as we have mentioned before, he did not know about chromosomes. The chromosomes are important because they are the physical basis of heredity. Chromosomes were described in Chapter 4 on cell division. In normal cell division each chromosome splits longitudinally and the halves separate into the two daughter cells. Since this splitting is accurate, the two halves are identical and the daughter cells are genetically the same. Obviously, such a procedure would not afford a mechanism for the separation of the members of pairs of factors. You will remember that Mendel's first law stipulates that the members of pairs of factors must separate into sister gametes. If the factors are borne in the chromosomes, then there must be a special kind of cell division in the formation of gametes. This is exactly what takes place. The special kind of cell division is called reduction division or meiosis in contrast to normal cell division or mitosis.

The term "reduction division" comes from another peculiarity of this division. In sexual reproduction two sex cells (gametes) unite to form a zygote. Each of the sex cells contributes a complete set of chromosomes (n). The zygote and the individual developing from the zygote have two sets of chromosomes ($2n$). If there were no reduction in the number of chromosomes, the next generation would have four sets, and so on. It is evident that a reduction in the number of chromosomes is necessary if all individuals of a kind are to have the same number of chromosomes. Meiosis reduces the number from 2 sets to one set (from $2n$ to n).

Reduction division occurs at only one stage in the course of a generation. This stage is just prior to gamete formation. To illustrate such a division, let us take the garden peas as an example. In peas, the chromosome number is seven. That is, there are seven chromosomes in a set ($n=7$) and the pea plant actually has $2n=14$ chromosomes in every

cell. These 14 chromosomes comprise two sets of 7 each and each set was derived from a different sex cell. Suppose the pollen came from a pure tall plant, and the egg from a dwarf plant. Then one of the chromosomes in one of the sets would bear a gene conditioning tallness, and there would be a corresponding chromosome in the other set bearing a gene conditioning dwarfness. These two chromosomes are said to be homologues. They correspond to each other, and each bears the same assortment of genes arranged in the same order. The genes for round and wrinkled seeds would be borne in a different pair of chromosomes. The genes for yellow and green would be borne in still another homologous pair, and so forth. Genes which condition alternate conditions such as yellow and green, round and wrinkled, tall and dwarf, are said to be alleles, and alleles always have the same relative position in a chromosome.

We have already seen that the gene for tallness must separate from the gene for dwarfness in meiosis. We have now seen that these two alleles occupy different chromosomes. The essential feature of meiosis, then, is the separation of the homologues. In order for this to happen consistently, the homologous chromosomes pair off during the meiotic prophase. The two homologues of a pair come to lie side by side in such close approximation that they resemble a single chromosome. Then the two homologues separate, each going to a different pole just as the halves of a chromosome go to different poles in normal cell division. In this way the two sets of chromosomes are separated and the chromosome number reduced by half. There is no division of chromosomes, but rather a separation of homologues.

Now, in our garden pea we had seven pairs of chromosomes. In the cross we are considering, tall \times dwarf we got seven chromosomes from the pollen and seven from the egg. Let us represent the chromosomes in the pollen as $a b c d e f g$ and the seven in the egg as $a' b' c' d' e' f' g'$. And let us sup-

pose that chromosome "e" carries a factor for tallness and chromosome "e'" a factor for dwarfness. In the zygote and throughout the plant all cells have all 14 chromosomes. The plant becomes tall because of the dominance of the gene for tallness. In the formation of pollen and eggs, meiosis takes place. In every pollen mother cell and every female spore mother cell the a b c d e f g chromosomes pair with the a' b' c' d' e' f' g' chromosomes. As "e" chromosome pairs with "e'" chromosome, the two alleles for height come together. The homologues are then separated and the allele for tallness is separated from the allele for dwarfness.

Thus, we have an explanation of Mendel's first law. But, what about his second law? The second law stipulates that the members of different pairs of factors segregate independently in gamete formation. This condition would be met with if the pairs of homologues separated without having any effect on each other, that is, at random. When chromosome "e" separated from chromosome "e'," the allele for tallness separated from the allele for dwarfness. At the same time chromosome "a" separated from "a'," "b" separated from "b'," "c" from "c'" and so forth. But it is a matter of pure chance as to whether a particular chromosome goes to one pole or to the other. For instance, the daughter cell which contains chromosome "e" with the gene for tallness may also contain chromosomes a' b' c d' f and g'. Any other combination is just as likely because the homologues separate at random.

For an example, consider the dihybrid in Mendel's eighth experiment (round yellow \times wrinkled green). Let us assume that the round vs. wrinkled alleles are located in chromosomes "a" and "a'" respectively while the yellow vs. green alleles are located in chromosomes "c" and "c'" respectively. If the round yellow variety is used as the male parent, the pollen will contribute chromosomes a b c d e f g including the two genes for shape and color of seed. The female parent

will contribute chromosomes $a' b' c' d' e' f' g'$ including the corresponding alleles. The hybrid plant will have 14 chromosomes in every cell. One of these will carry a gene for yellow, another will carry the allele (green) and will be its homologue. A third chromosome will carry a gene for round, and a fourth will carry the allele wrinkled. The other ten chromosomes will carry still other genes not considered here. At meiosis, " a " pairs with " a' ," " c " with " c' ," etc. But the homologues separate at random. Considering these two pairs of chromosomes only, the following combinations are possible: $ac, ac', a'c, a'c'$. Cells of these four classes should occur in approximately equal numbers.

Let us represent the gene for yellow by Y and its allele by y , and the gene for round by R with its recessive allele by r . The chromosome classes above would then have the following genic constitution: YR, Yr, yR, yr . These four classes apply equally well to both pollen and the eggs. If we self-fertilize the hybrid, we combine pollen and eggs at random. The following combinations of F_2 zygotes then are possible:

	<i>Pollen</i>	<i>Eggs</i>	<i>F₂ zygotes</i>	<i>F₂ characters</i>
<i>YR</i>	<i>YR</i>	<i>YR</i>	<i>YYRR</i> (1)	Yellow round
	<i>YR</i>	<i>Yr</i>	<i>YYRr</i> (2)	" "
	<i>YR</i>	<i>yR</i>	<i>YyRR</i> (3)	" "
	<i>YR</i>	<i>yr</i>	<i>YyRr</i> (4)	" "
<i>Yr</i>	<i>Yr</i>	<i>YR</i>	<i>YYRr</i> (5)	" "
	<i>Yr</i>	<i>Yr</i>	<i>YYrr</i> (6)	Yellow wrinkled
	<i>Yr</i>	<i>yR</i>	<i>YyRr</i> (7)	Yellow round
	<i>Yr</i>	<i>yr</i>	<i>Yyrr</i> (8)	Yellow wrinkled
<i>yR</i>	<i>yR</i>	<i>YR</i>	<i>YyRR</i> (9)	Yellow round
	<i>yR</i>	<i>Yr</i>	<i>YyRr</i> (10)	" "
	<i>yR</i>	<i>yR</i>	<i>yyRR</i> (11)	Green "
	<i>yR</i>	<i>yr</i>	<i>yyRr</i> (12)	" "
<i>yr</i>	<i>yr</i>	<i>YR</i>	<i>YyRr</i> (13)	Yellow round
	<i>yr</i>	<i>Yr</i>	<i>Yyrr</i> (14)	Yellow wrinkled
	<i>yr</i>	<i>yR</i>	<i>yyRr</i> (15)	Green round
	<i>yr</i>	<i>yr</i>	<i>yyrr</i> (16)	Green wrinkled

Of the 16 combinations in the table, some are genetical duplicates. Actually, there are nine different classes as follows: (1), (2, 5), (3, 9), (4, 7, 10, 13), (6), (8, 14), (11), (12, 15), and (16). These different classes differ genetically and are called genotypes. The genetical constitution of an individual is its genotype. Actually there are only four classes which can be distinguished by observation. These are round yellow, wrinkled yellow, round green, and wrinkled green. These four classes are phenotypes. The phenotype of an individual is its appearance. The phenotype is determined by the interaction of the genotype and the environment.

Mendel worked with seven pairs of characteristics. Actually there are hundreds of recognizable character differences in garden peas. Most of these are conditioned by single gene differences. This means that each of the seven chromosomes has numerous genes. It can be shown genetically that these many genes are arranged in linear order throughout the length of the chromosome (Fig. 7). The important feature of this situation is that the genes in the same chromosome behave as though they were linked. The phenomenon is called linkage. If a particular chromosome moves to a particular pole at meiosis, all of the genes which it contains move as a unit to that pole. These genes are actually linked physically to one another.

Linkage is seldom complete, however. When the homologues pair during the first stages of meiosis, they come in such close approximation that there is usually an exchange of material from one chromosome to another. This exchange of material is called crossing over. Crossing over normally occurs whenever homologues pair normally. Since this exchange of material is regular, the only effect of linkage is to reduce the size of the recombination classes. The amount of linkage varies depending upon the position of the genes. This is due to the fact that the crossing over occurs at ran-

dom. If two genes are close together on the chromosome, the chances of a crossing over occurring between them is less than if the genes were farther apart. Thus, if two genes are close together the recombination classes are very small. If the genes are far enough apart, the recombination classes may be nearly as large as the parental combination classes. This phenomenon of linkage and crossing over is of extreme importance in plant and animal breeding.

In connection with the problem of linkage it would be well to mention the backcross. The backcross is a very powerful tool for the plant or animal breeder. To illustrate a case, let us suppose that a breeder finds a variety of sweet pea which is fairly resistant to stem streak, a virus disease of sweet peas. He wishes to introduce this valuable characteristic into a particular variety of Late Spencer sweet peas which has particularly nice color and flower shape. The procedure would be to cross the two varieties of sweet pea. The F_1 secured is then backcrossed to the Late Spencer. The progeny of this backcross are examined and those plants which resemble the Late Spencer most closely and also have the character for disease resistance are again backcrossed to the Late Spencer parent. Again the progeny are selected and again the backcross is made. If the process is repeated long enough, it is theoretically possible to produce a new variety with all the flower characteristics of the desired Late Spencer plus the disease resistance. This is possible even if the disease resistance is closely linked with some of the genes for undesirable flower characteristics. If linkage is close, however, the process of selection and backcrossing must be carried on longer and with a larger number of selections for each generation. This is possible because crossing over taking place at random will eventually free the character for disease resistance from the other genes. Selection must be carried out carefully, however, and artificial inoculation of the virus disease is desirable in order to be sure that the selec-

tions are resistant. This requires a special technique, but other desirable characters besides disease resistance can be introduced by the same process of backcross and selection.

Some characteristics are conditioned by two or more genes. Certain purple-colored sweet peas require a dominant gene for the color chromogen and another dominant gene for the enzyme to activate the color gene. When either or both of these dominant genes are absent, the flowers are white, but if both are present they are purple. The result is nine purple to seven white. If the sixteen individuals in the above dihybrid experiment are examined, the 9:7 ratio can be seen. Nine are smooth yellow showing the presence of both dominant genes; the other seven lack one or both of the dominant genes.

Genes have been shown to control chemical reactions in the developing organism in such complex structures as the anthocyanin pigment and the chlorophyll formation, which are physiological Mendelian characters. Recently the natural prostrate growth of corn, called lazy corn, has been shown to be the result of a gene causing the growth hormone to be more concentrated at the upper side of the stalk. Transmission of physiological characters has been studied much less than the structural characters, but when we think of the advancing knowledge of physiology, the field for breeding becomes almost unlimited.

Luther Burbank made thousands of crosses and produced a number of valuable plants. He was not primarily interested in the parents of a new plant, and, therefore, kept few records. He used grafting and other vegetative means of propagation to grow his creations long enough to decide on their merit. He might graft pieces from six hundred seedlings on a single tree where they would grow fruit in a year or two to demonstrate their value. He had an unusual ability to select desirable plants from millions of undesirable ones, while they were young, and before other people could

detect differences. Burbank gave all his effort toward spectacular "new creations" whereas Mendel made fewer crosses, kept excellent records, and contributed a scientific law that is useful to all plant breeders.

Many people have made outstanding contributions in the field of plant genetics, a knowledge of which would suggest problems to the reader, but this work cannot give such descriptions since, in most cases, the aim of the experiment was the further development of the science of plant breeding or the improvement of farm crops. One of the most interesting and important projects is that carried on at Cornell University, namely, the growing of all the known genetic strains of corn year after year in order that they may be available to plant breeders. It is a living museum well worth seeing. The United States Department of Agriculture has extensive projects in all of the common farm crops.

Breeding of the garden plants, and especially the little-known ones, has had little attention, but it appears to be a fine field for work. Frequently plants respond readily to improvement of breeding and selection. Select flowers of medium size to begin work, and as the technique advances, smaller flowers may be used. Remove the anthers, snipping them with a pair of fine scissors before they open, and cover the flower with a bag to prevent pollination from an unknown plant. When the stigma is ripe, get pollen from ripe anthers of the desired plant, the flowers of which have been covered to prevent stray pollen getting with the desired pollen. Then apply the pollen to the stigma of the emasculated flower, after which the flower must remain covered until the seeds begin to form. A camel's hair brush may be used to transfer the pollen. In many cases the pollination may be unsuccessful; perhaps the stigma was not receptive or in cases where the two plants differ in variety the pollen may grow poorly. The pollinated flower should be labelled and careful records should be kept of the parents.

It has been known for a long time that hybrids have greater vigor than either of the parents, but little use was made of the fact until recently. It is believed that more vigor is given to an organism by dominant characters than by recessive ones. Since the hybrid has a very much higher percentage of its characters conditioned by dominant factors, it is more vigorous, but, for the same reason it does not transmit its vigor to the offspring. Where self-pollination is the rule, more and more characters become fixed. The hybrid field corn grown in 1943 was about 50 million acres in the United States with the twelve corn states planting it in 78 per cent of their acreage, while the larger growers use hybrid sweet or sugar corn almost entirely. "Seed" is purchased each year from specialists who grow it. A high percentage of the chickens grown today are cross-breeds or hybrids.

The production of hybrids for vigor in garden plants has not been followed by anyone, to the author's knowledge, but it should be a very promising field. Seeds could be used for annual flowers as they are used in corn, but in many other cases the hybrids could be propagated vegetatively.

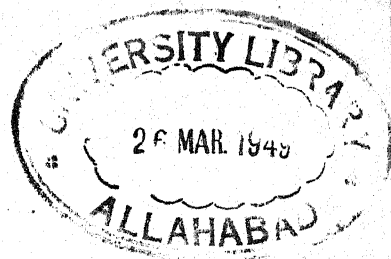
Petunia, fox-glove, flowering tobacco, roses, and peas make interesting plants for beginners. Time and patience are essential. It is not a pastime for an odd week-end, but one that must have frequent attention when the flowers are receptive, at which time several hours may be used with little progress. The United States Department of Agriculture Yearbook for 1937 describes special techniques for different garden flowers.

If thought, time, and effort are used, and careful records are kept, the reward should measure well above the average for the effort expended. The work of Mendel in the very small garden shows that extensive equipment and space are unnecessary. The changing of a plant or flower by a well-planned experiment is a great thrill. Most of the improve-

ments can be passed on by seed or by vegetative reproduction to friends.

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Chapter Nineteen

HEREDITY AND VARIATION IN PLANTS

In the previous chapter we have seen how crossing and selecting may lead to the production of new and improved varieties. We also discussed some of the fundamental reasons for getting such results. The discovery of Mendel's laws and cytological work on the behavior of chromosomes has removed plant and animal breeding from the realm of superstition and magic and established it as a science.

But, we must not forget that plant breeding has been going on in some form or other for thousands of years. For all our new knowledge, we have not added a single new *staple* food to our diet since the stone age! Wheat, barley, rice, bananas, cocoanuts, dates are all very ancient crops, and are staple crops today. Archaeologists who have studied the upper basin of the Nile (Dorsey, De Rustafjaell and others) believe that barley was grown in Egypt at a time when Northern Europe was still covered with ice (10,000–15,000 years ago). While corn and the potato may not be such ancient crops, they were developed by stone age Indians in the Americas. Stone age farmers improved their crops mainly by selection, but the results that they achieved attest their diligence. Stone age men domesticated and improved all our major crops. The American Indians had all the major kinds of corn that we have today. They had pod corn, pop corn, dent corn, flint corn, sweet corn, red, blue, purple, white, and yellow corn. For all our knowledge of the ten pairs of chromosomes, our use of X-rays and our intensive breeding, we have contributed much less toward the production of a staple crop than stone age Indians.

We generally expect the offspring to resemble its parents. In fact, this principle is so pronounced that it has been recog-

nized by man from the period of earliest history to the present. For this reason, selection of desirable plants and animals for use in reproduction has been practiced since prehistoric times.

We speak of such resemblance of the parent and offspring as evidence of a close fundamental relationship by saying "a chip of the old block," "blood will tell," or "like begets like." Actually much remains to be done by the men of research before the whole story of heredity can be explained, but many of the old ideas are remarkable for their accuracy considering the knowledge of that day of cell structure and reproduction. If chromosome structure in Chapter 4 and sexual reproduction in Chapter 10 are studied, it will be clear that the sex cells might be called "chips" and that the chromatin is a special kind of protein that passes from cell to cell during their divisions, from generation to generation.

Heredity and variation are so closely associated in reproduction and development that it is difficult to treat them separately. Heredity is the transmission of the characteristics of the parents to the offspring. If this law alone operated, all organisms would be alike. However, it will be seen from the discussion of fertilization in the previous chapter that the chance of an individual's having the same set of dominant genes as either parent is very remote. For the same reason the offspring of the same parents are all different, but all resemble the parents in some of the characters. Only in identical twins and in asexual methods of reproduction should the genes be the same in two or more individuals, and asexually produced individuals do resemble each other more than do individuals that are produced sexually. The several peas in a pod each come from a different pair of sex cells and therefore produce plants which differ in some of their characters. The small link of protoplasm (the sex cells) connecting the parents with the offspring bears the chromosomes which are the physical basis of heredity.

Hybridizing, and plant breeding generally, depend on the laws of heredity for their success. It is a force of stabilization which would result in all organisms being exactly alike if variation did not take place too. If all organisms were alike, crossing would have no value.

Variation is the tendency for all organisms to be different. It is the exact opposite of the tendency of heredity. Variation may be due to factors within the organism or to the environment. Evidence of variation is all around us; no two leaves are exactly alike, flowers are all different, and the Government uses the Bertillon system of identification because no two human beings have the same fingerprints.

Variations may be divided into two classes: first, due to the combination of two different sets of genes at the time of fertilization, resulting in different groups of characters in each individual. No two children of a family are alike or look alike, hence they show variation due to different combinations of genes. Variations caused by crossing will breed true, but it must be remembered that the Mendelian laws will be obeyed for many of the characteristics. The vast possibilities for combinations of chromosomes is a fruitful field for variations.

In an unknown number of cases, variations are caused by the mixing of the chromosomes. The one most studied is the cross-over, where the homologous chromosomes exchange a portion of their length. Some of the genes of a chromosome from the male parent will take the place of the homologous genes in the chromosome from the female parent. Cases of cross-over are discovered by studying the transmission of characters known to be on the same chromosome.

A mutation is a second class of internal variations. A mutation is sudden and breeds true. It appears to be a change in a gene, brought about by some external influence. Often a bud grows into a different kind of branch, or bears different flowers or fruit. Thousands of bud mutations have

been described in scientific literature in recent years. It has become an important field of study, and many attempts have been made to increase the number of mutations.

Two important commercial apple bud mutations (called sports) appeared on trees of the Delicious variety; one was called the Golden Delicious and another was the origin of the Starking variety. Nursery men paid fancy prices for these sports. These finds caused agricultural periodicals to suggest careful search for bud sports.

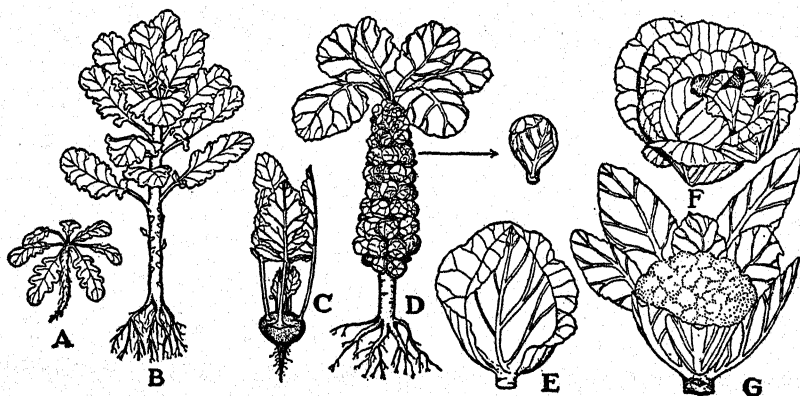


FIG. 23. Domesticated varieties derived from the wild cabbage, *Brassica oleracea* (A), a native of Europe. B is kale, *Brassica oleracea acephala*; C, kohlrabi, *B. oleracea caulorapa*; D, Brussels sprouts, *B. oleracea gemmifera*; E, pointed-head cabbage, *B. oleracea capitata*; F, round-head cabbage, *B. oleracea capitata*; G, cauliflower, *B. oleracea botrytis*. (From Transeau *et al.*, Textbook of Botany. By permission of Harper Bros., 1940.)

Fruits with commercial value have long lists of bud sport varieties. Hundreds of varieties of bud sports of roses and thousands of varieties of chrysanthemums have been developed. It must be remembered that these are the only ones recorded in literature. Most people do not observe their plants with the care necessary to detect differences, and doubtless many have been observed but not recorded. With the increased interest in the science of gardening we may expect the number of reported bud sports of plants to be amazing. Any unusual shape, size, color, or rate of growth should be studied as a possible valuable bud sport.

The wild ancestor of our common cabbage (Fig. 23) and its relatives, kale, kohlrabi, brussels sprouts, and cauliflower illustrate the horticultural development by mutations.

Mutations are very important in plant improvement, but in nature they are seldom noticed. For this reason many experiments were made to find artificial methods to increase their number. Today, we may multiply the number of mutations in many cases by a thousand times with artificial treatments. X-ray treatment of seeds or growing points was one of the first methods employed. Now methods more nearly available to everybody are fully as successful. Extreme cold, controlled heat, old age, and numerous chemical treatments are used extensively. Another type of change, polyploidy, will be considered later in this chapter.

Johansen thought that by always selecting individuals of a desirable extreme character, a new strain could be developed, but he found that these selections always varied back toward the original or normal form. He selected small beans and large ones, but found in both cases that their average size was not the size of the parents, but the average tended toward the normal average. He thought his beans might have a mixed ancestry, and therefore he bred nineteen pure lines. A pure line is the progeny of a single self-fertilized homozygous individual. The results for the pure lines with either large or small beans proved to be the same as for the beans that were not of a pure line.

The pure line technique has become very important in much of the plant breeding since it produces individuals more nearly uniform, which can be used as checks for comparison with the modified strain. In careful work pure lines are also used for crossing.

Variations due to the environment will not breed "true" as was true for variations caused by an internal or chromatin change. Large or productive plants in a good environment will lose these desirable characters under unfavorable con-

ditions. However, plants grown in a good environment produce larger seeds, which supply more stored food to the seedling resulting in a more rapid growth of the seedling.

Many plants are quite sensitive to a location change. For instance, corn may fail to grow well if the "seed" is taken a hundred miles or less from the place in which it has been grown. Plants that are highly successful in one garden may fail in the adjoining garden because of the difference in the soil or some other change in the environment brought about by the gardener.

The other type of change, polyploidy, involves the addition of a whole new set of chromosomes. Polyploidy is sometimes called mutation also, but in a strict sense mutation refers only to gene changes. A duplication of the chromosome set is usually accompanied by an increase in the size of the cells. The usual number of chromosomes, as we have seen, is $2n$. In polyploids, the number may be $3n$ (triploid), $4n$ (tetraploid), $5n$ (pentaploid), $6n$ (hexaploid), and so forth. Plants with an odd number of sets are not able to have normal meiosis and are highly sterile. Sometimes changes involving a single chromosome occur. This results in plants with $2n + 1$ or $2n - 1$ chromosomes. A $2n + 1$ plant is called a trisomic. A $2n - 1$ plant is known as a monosomic. The phenomenon is called aneuploidy. Trisomics and monosomics in general are semi-sterile.

High temperature during the development following the fertilization of the egg has produced polyploidy in cereals. Wheat or rye is pollinated and kept in a constant temperature of 25°C . for a twenty-hour period, which is necessary for the growth of the pollen tube to the egg cell and for fertilization. While the first divisions of the fertilized egg are taking place, the temperature is increased to 43°C . for twenty to thirty minutes, after which it is returned to a normal greenhouse. This high temperature is so near the maximum that the plant can withstand, that it is best to keep a

high humidity to prevent injury. We are unable to explain the way the high temperature influences cell division.

Perhaps the most striking and the most successful chemical treatment for inducing polyploidy is the use of colchicine, a poisonous substance from the bulbs of fall-blooming crocus. This chemical had been known for some time to check cell division of animal cells, but not until 1937 was its potent effect on plant cells demonstrated. Dr. Nebel and Dr. Ruttle, his wife, at the New York Experiment Station at Geneva and Dr. Blakeslee of the Cold Springs Harbor laboratory of the Carnegie Institute, working independently discovered that colchicine caused a doubling of the chromosome number. The explanation of these results does not go very far but in some way the chemical prevents the formation of the cell wall that normally separates the chromosomes after they have divided in cell division. In other words, the division is incomplete. This may be repeated several times; Levan in 1938 reports cells of the root-tip of onion with "probably" about 500 chromosomes. As the chromosomes increase in number, the size of the cells increases and at the same time the organism and all of its parts increase in size. Apparently, however, cell division becomes slower and more difficult as the chromosome number increases, causing the death of the organism when too large. At present the successful use of colchicine appears to depend on a treatment that is strong enough to cause the chromosome number to double once in a large proportion of the cells of the treated portion. Stronger treatment is lethal. A treated bud that forms a branch, or a seed forming a plant with the increased number, can be used for vegetative reproduction or in seed formation.

Methods of using colchicine have been described by Drs. Blakeslee and Avery of the Cold Spring Harbor Laboratory, some of which are illustrated by Plate VIII. Seed treatment is probably the easiest and most effective. They have in-

duced doubling of chromosomes in a number of plants including: *Datura*, *Portulaca*, *Cosmos*, *Phlox*, *Petunia*, *Digitalis*, and *Cucurbita*.

A very successful student experiment with radish seeds was carried out by putting dry seeds in a $\frac{1}{2}$ per cent solution of colchicine for six hours. The seeds were then washed in water and planted. Other concentrations and length of soaking period can be tried. Not all seeds require the same treatment. In this experiment nearly 50 per cent of the treated seeds showed signs of having been properly treated. About 25 per cent of the treated seeds were killed and about the same number appeared as normal. The treated seedlings had the characteristics of the cosmos seedlings shown in Plate IX. The plumule and the root are very slow in starting to grow, and may be so severely injured that the plant will die before it begins to grow properly. After the seedling stage growth is better and the plants are likely to survive. The leaves are often wrinkled, indicating regions with larger cells due to the increased chromosome number.

Simple methods have been found to detect the plants in which a mutation is caused by colchicine. In addition to abnormal appearance of the leaves, microscopic examination shows the leaves to have larger cells, and as a direct result fewer, larger stomata in a given area. Pollen studies made of most of our common plants show that the colchicine treatment causes the pollen grains to be uniform and larger in size and to contain increased numbers of chromosomes.

The importance of these simple methods of inducing polyploidy may prove that plant improvement by this method may be very nearly as important as were Mendel's laws. Larger flowers, fruits, seeds, stems, leaves, and roots have been grown in this way. It has also been used in many cases to build closely related plants with a difference in their chromosome number into plants with a like number, which is necessary before they can be crossed successfully.

Dr. Darrow and his coworkers at the Beltsville Md. Research Center of the United States Department of Agriculture have used colchicine to build an amazing series of strawberry plants. *Fragaria vesca* has 14 chromosomes, *F. elatior*, 42, *F. chiloensis* and *F. virginiana* have 56. The cultivated strawberry is directly derived from the last two and also has 56 chromosomes. In order to improve the cultivated strawberry in flavor, in disease resistance and drought resistance, in shipping quality, etc., certain characters from all the above species were desirable. Fertile crosses can be made only with plants having the same chromosome numbers, therefore, they set out to double the chromosome number of those with larger as well as those with smaller numbers. By use of colchicine and hybridizing they have actually made to order a whole series of plants to be used in improving the strawberry.

In all plant breeding or genetical work the various methods of attack must be considered in order to select the one best adapted to the problem and to the facilities of the worker. It is well to keep in mind that by careful consideration more than one good method of investigation will be available to solve most problems. It is best to use as many methods as are practicable.

Careful observation of plants is of first importance. After a mental picture of the desired plant has been formed, the plants with these desirable characteristics must be sought. Many worthwhile improvements have resulted from the selection of plants produced by nature, as foundation stock. Not all plants breed true, but here we must find plants with the qualities we want and strive to develop them.

Plant breeding is the method most commonly considered to be important, but it might be well to bear in mind that actually this method is best when it is the total of all methods. By this method we usually think of cross-pollinating of flowers, which is the fundamental part of the sys-

tem, but all the other methods must be used to get the maximum of value from the breeding work. Plant breeding usually includes careful morphological studies of the whole life history of the organism.

Cytological studies are made when the facilities are available because this is a study of the chromosomes—the physical basis of heredity. Chromosomes are the smallest physical structures that can be seen which are responsible for the type of organism. Cytology is valuable in determining the number of chromosomes, and often in showing reasons for the failure of crosses. Pollen grains, eggs, and even sperms may be studied in this way.

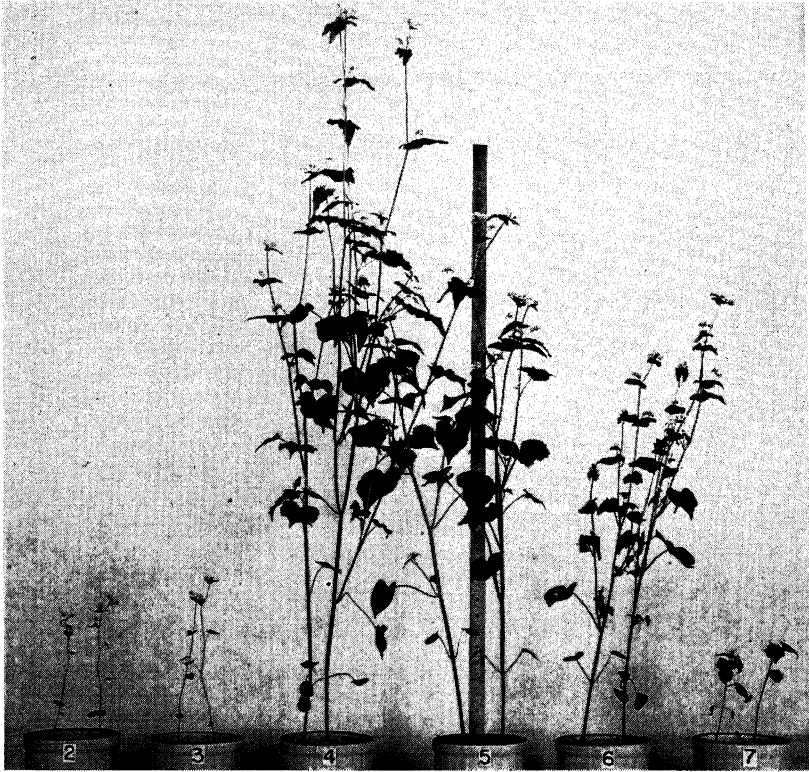


PLATE XI. Buckwheat grown in sand with added mineral salts compared with soil check, No. 5. No. 2, tap water; No. 3, N omitted; No. 4, all essential salts; No. 6, B omitted; No. 7, K omitted.

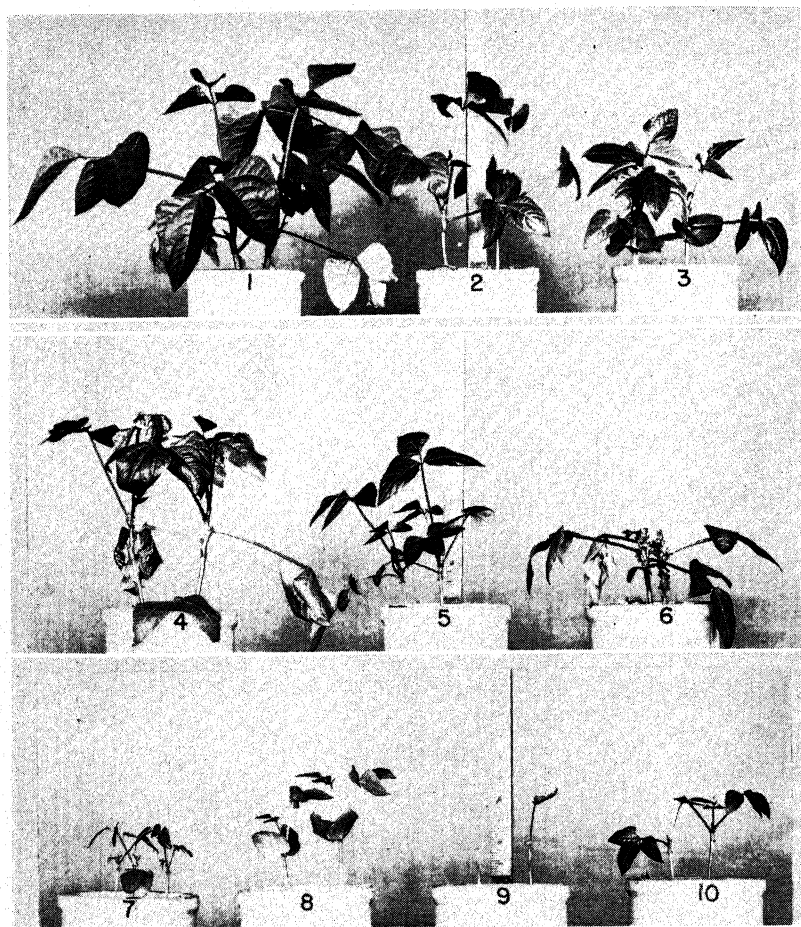


PLATE XII. Cowpeas grown in sand with all the essential mineral salts in No. 1, compared with soil in No. 2. No. 3, S omitted; No. 4, Mg omitted; No. 5, K omitted; No. 6, Ca omitted; No. 7, distilled water; No. 8, tap water; No. 9, N omitted; No. 10, P omitted.

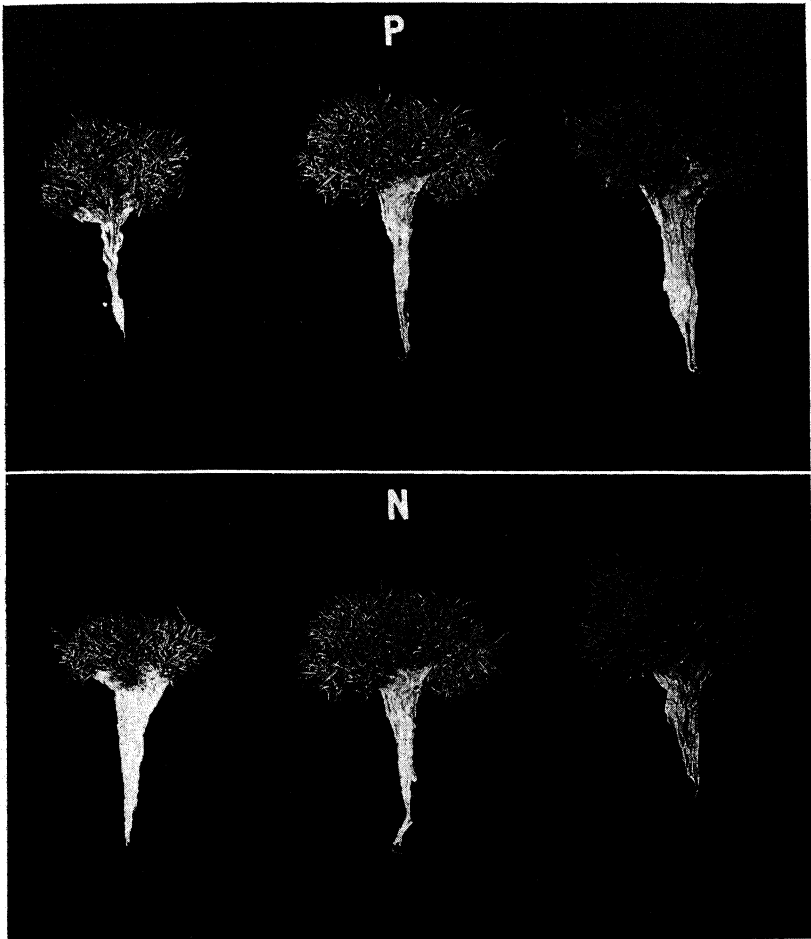


PLATE XIII. Effect of low (left), medium, and high (right) concentrations of phosphorus (top), nitrogen (bottom) on cut creeping bent grass. (From United States Golf Association Green Section.)

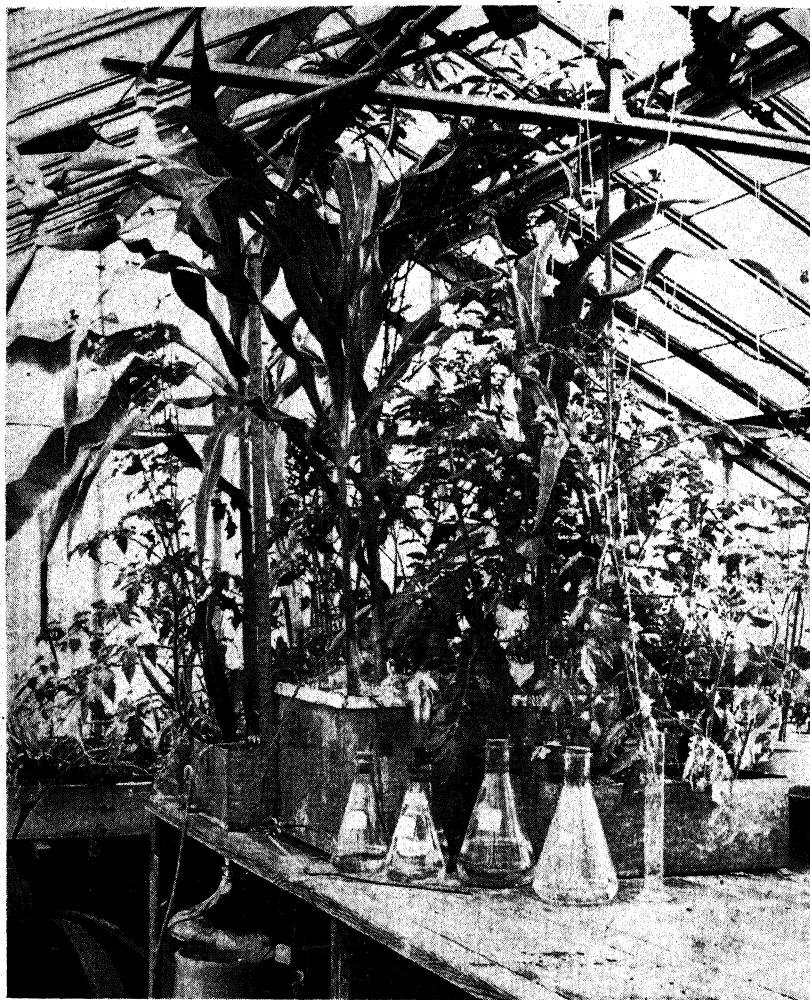


PLATE XIV. "Hydroponics" in the greenhouse. Foreground plants in sand. Middle tank with plants in rack. Last, gravel with siphon to remove the solution when it reaches the top of the siphon. Supply bottle in the rear.

Chapter Twenty

PLANT HORMONES

The nature of growth has been as eagerly sought as has been the explanation of life itself. They are certainly closely related. But how are roots, shoots, and flowers formed? Why do most shoots grow upward and most roots downward? During the past fifty years the discoveries of hormones, and their effect on growth, have explained some things about growth but have stimulated even greater interest in the problem.

Hormones are substances which are produced in one part of an organism, and are transported to another part where they influence a specific physiological process. Many hormones are known in animals, such as those secreted by the thyroid gland, sex organs, etc.

Plant hormones have been called growth regulators, growth substances, auxins, growth hormones, and phytohormones. It should be noted that they are used to condition the growth of the organism rather than to build its structure, as mineral salts, sugars, and proteins are used. Hormones are used in extremely small quantities; for example, if a trillion oat plants were treated with a dilute solution made from an ounce of auxin, a pronounced growth curve would occur on each of them. Auxin-a has been shown to be active in water solution in one part to 110,000,000 parts of water.

Besides hormones, other substances which influence growth are common in plants in small quantities, as enzymes, vitamins, and bios. These differ from hormones in that they usually remain where they are formed to influence a special process. Enzymes increase the rate of an action already taking place. They are widely distributed through the

plant, in fact, some kinds may be in every living cell. The action of many plant enzymes is similar to the action of animal enzymes, as is the case of the digestion or oxidation of food. Starches, proteins, and fats are common in plants and in animals, and are broken into simpler forms by enzymes in both groups. Many of the vital activities of all organisms are regulated by enzymes but the details of the regulation are not understood.

Vitamins are probably as essential to plant as to animal life, but plants are able to synthesize them. It is common knowledge that most vitamins for the human diet must come from plants directly or indirectly. Some recent research work suggests that the bacterial life (or its products) of the soil aids the plant in this synthesis. Plants grown on a soil rich in organic matter were higher in vitamin content than those grown on a poorer soil. A supply of stored food in the cells but not light is essential for their production.

Some plants grown in nutrient solutions have shown a favorable response to added vitamin B₁. Since plants can make vitamins and therefore have them at all times, it has been difficult to study their functions in the plant. Recently certain plants (*Carnellia*, *Eucalyptus*, and others) have been found, at least under certain conditions, to be able to synthesize less than the optimum amount of vitamin B₁ for their best development. This has been highly popularized and advertised, but it should be kept in mind that most plants in rich soil produce enough for themselves. In such cases soil or plant applications would be of no value. When vitamin B₁ is added to test its need in a particular plant, check plants should be left for comparison.

Bios is a growth substance found in relatively large amounts in yeast and in many other of its relatives, the fungi. When applied to higher plants it stimulates rooting. Bios has been found in the dividing cells of flowering plants. It appears to be important in embryonic cells, rather than

in the cells which are elongating or those that are fully grown. These regions are described in Chapter 5. Embryonic cells grow by increasing the amount of protoplasm, but elongation is largely the result of swelling by increasing the amount of water which forms large vacuoles.

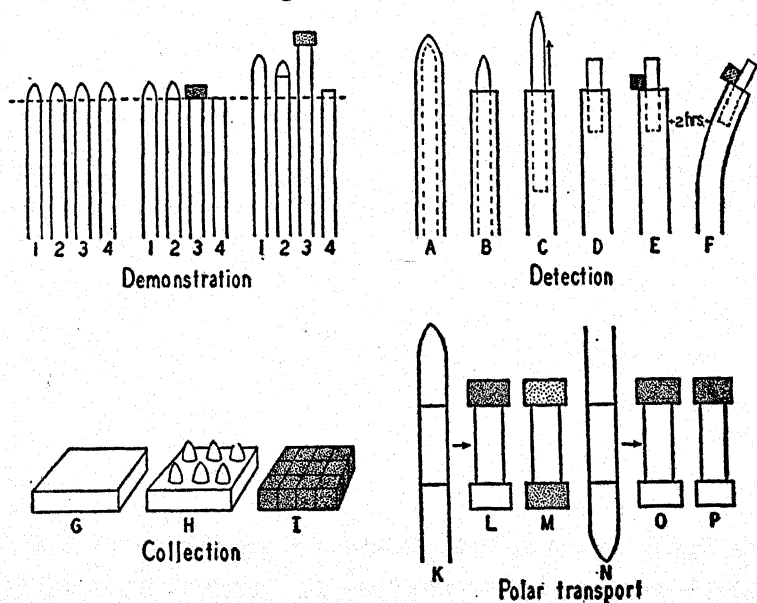


FIG. 24. Auxin (its concentration in the agar is shown by various shades of dotting) and growth of *Avena* coleoptiles.

Upper left. Demonstration of auxin formation by coleoptile tip. Plant No. 1 is left intact; Nos. 2, 3 and 4 are decapitated. On No. 2 the cut tip is replaced; on No. 3 auxin (in agar) is stuck. The right hand set of four plants shows the effect of this treatment on growth after three hours.

Lower left. Collection of auxin from cut coleoptile tips. For a period of two hours 6 coleoptile tips are placed (H) on a layer of agar, $6 \times 8 \times 1$ mm. (G). After removal of the tips the agar contains auxin diffused out of the tips, and is cut into 12 blocks (I).

Upper right. Scheme or test method for auxin. Coleoptile (A) is decapitated leaving the primary leaflet (B). The latter is partly pulled out (C and D) and an agar block with auxin is placed on one side of the cut surface of the coleoptile (E). Two hours after application of the agar the resulting curvature (F) is measured.

Lower right. Demonstration of polar transport of auxin. On the apical surface of a coleoptile cylinder cut from the seedling (K) a block of agar with known auxin concentration is placed and the basal surface is placed on a block of pure agar (L). A few hours later the greater part of the auxin will have been transported towards the lower block (M). If the coleoptile cylinder has been reversed (N and O) no transport whatsoever is detectable; all auxin remains in the upper block, in contact with basal cut surface (P). (From The Botanical Review, vol. 1, pp. 162-182. By F. W. Went, 1935.)

The exact chemical composition of the auxin-a and -b hormones of plants is known, even though they occur in dilute amounts. However, it is possible that many different hormones exist. Organic chemicals have been found which cause reactions so similar to those caused by the plant extracts, that it is believed they have the same or a similar basic chemical complex. Chemicals that are easily procurable and easy to use are indole-3-acetic acid and phenyl-acetic acid. These may be purchased also in prepared dilutions from many advertisers in newspapers and garden magazines. More than fifty organic substances have been found to cause bending similar to that of the auxins and the above chemicals. Auxin-a has the formula $C_{18}H_{32}O_5$ and auxin-b has the equivalent of one molecule of water less, that is, $C_{18}H_{30}O_4$.

The hormones or chemicals from which they are formed are probably in the seeds. The hormone is abundant in the coleoptile (Figs. 4 and 24) of the oat seedling, which has been used commonly for its study. Hormones are synthesized also in leaves, perhaps in root tips, and in fungi.

To demonstrate the influence of auxin, oat seedlings are grown in darkness, at a constant temperature of about $22^{\circ}C$. until the shoots are about $1\frac{1}{2}$ inches long. The tips of some of the coleoptiles may be removed in red or orange light and placed on small sheets of agar (Fig. 24). The tip of a coleoptile is shown pushing through the soil in Figure 4, and the older seedlings show the coleoptile after the plumule emerges from it. After the auxin has moved into the agar, small pieces may be placed on the cut surface of other coleoptiles, to which the auxin will pass from the agar, and cause increased growth on the side receiving the auxin. This is the method used to demonstrate the small amount of auxin necessary to cause bending, described at the beginning of this chapter.

The same figure shows an important characteristic of

growth hormones, namely, they move in only one direction through plant tissue. The only known difference in pieces of tissue similar to the coleoptile in L and in O is a very slight electrical charge, but the auxin does not flow in a root to shoot direction.

The rate of movement of auxin is much too rapid to be due to the diffusion of its molecules. It may move at the rate of an inch in $2\frac{1}{2}$ hours, with little influence of temperature so long as it is favorable to growth. The amount translocated in a given time is influenced much more by temperature. The maximum is between 30°C . and 35°C . Many experiments like the above and others indicate that the movement is related to the movement of the cytoplasm inside the cells.

Auxin influences growth in various ways in different parts of the plant. Stems are elongated by its presence. The cell walls lengthen, perhaps by stretching more freely. If the auxin is equally distributed on all sides of the stem it will grow straight, but if more accumulates on one side, growth will be greater there, resulting in bending toward the side of lower concentration. Two types of bending have been extensively studied. Stems grow upright because auxin moves downward, and, therefore, becomes more concentrated on the lower side which gives the lower side increased growth and forces the stem to grow upright. Auxin tends to move away from the lighted side of a plant. If a plant is placed in a window it can be shown that the auxin is more concentrated on the side away from the window which is the side that grew more rapidly.

The role of auxin in root growth is not so clear. Auxin is present in the root in a more dilute condition than in the growing stem. Authorities are not agreed on whether the auxin moves from the shoot to the root or whether it is synthesized in the root. It appears to stimulate root growth in very minute amounts and to retard growth in larger amounts.

In this way horizontal roots accumulate auxin on the lower side, which results in the optimum condition for growth on the upper side. This explains the downward growth of roots.

Even more interesting is the influence of the synthetic hormones on the rooting of cuttings. The initiation of roots requires stimulation supplied by the growth hormones and a few other chemicals which cause an accumulation of the second hormone, called rhizocauline, at the cut surface from which the new roots start. Roots present on the treated material would be killed by the treatment. Plate X shows the conclusive results of rooting after treatment of holly cuttings.

Cuttings should be made normally, then placed in the chemical solution (2 to 10 parts in 100,000 parts of water) for 10 to 72 hours. The strength and time should be varied to find the one giving the best results for the particular plants at the particular time of year. A low rate of transpiration from the cuttings gives best results.

Lanolin paste has been used as a base to carry the rooting hormone, when it can be applied on the cut surface. Rooting compounds can also be purchased mixed with an inert powder, which can be applied to the fresh cuttings, after which it can be placed in the cutting bench at once.

The values of stimulating the initiation of roots on cuttings are most important where the untreated ones root with difficulty. Here a higher percentage of cuttings root, and a greater number root in a shorter time.

Roots, stems, and leaves have been induced to grow roots by this treatment. Hormone action on buds was mentioned in connection with pruning. In most plants the terminal bud secretes the most hormone. It moves downward stimulating the elongation of the stem below, but it also inhibits the growth of all lower buds. This has been studied by many people but the details of this growth control are not understood. It appears to be an interaction of more than one sub-

stance. If the terminal bud is removed, the inhibition of the remaining top bud will disappear. The same type of inhibition can be shown for sprouting potatoes. If a tuber is cut into cross section pieces with a bud on each piece, they will all grow if placed in a favorable condition for sprouting.

Hormones are being used for commercial purposes in such cases as the spraying of fruit trees to delay the falling of fruit. It is not known whether the falling is due to the presence or to the absence of a natural plant hormone. At present it appears that a very small amount of spray solution of naphthalene acetic acid or naphthalene acetamide on the stem of an apple will prevent the formation of the plate of cork cells across the stem (called the abscission layer), the weak point at which the fruit breaks from the tree. The whole tree may be sprayed but the stems of the fruit must be covered. It retards the fall of the leaves for a shorter time than the fall of the fruit.

Other applications have been attempted with success. It is not too much to expect that we may learn to use hormones in many ways, among which might be, to grow short stems longer, to prevent long stems from growing so long, to prevent the drop of flower buds, to inhibit the growth of certain buds, and to stimulate the growth of others.

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Chapter Twenty-One

SOIL IMPROVEMENT

Good root growth is necessary for healthy plant growth. It is easy to see how important the soil becomes in root development, since the roots must obtain water and mineral salts, and grow in the soil, pushing between the soil particles, and finally, as they grow in diameter, pushing larger masses of soil aside. The soil has been explained as a complex mass in Chapter 7, and it is safe to say, that any kind of improvement will be beneficial in more than one way. Most soils can be improved at a small expense if the effort is continued over a period of time.

Soil with a good texture is of a loose, crumbly consistency, which allows proper aeration for root growth and the increase in the growth and the number of soil organisms. It must be remembered that as the activity of the organisms increases the humus is destroyed more rapidly. With its increased growth, however, the root adds more humus as it decays. Pavlychenko of the University of Saskatchewan, found that single plants of grass had a root system with a total length of 300 miles, but no root was more than 7 feet long. A total length of 150 miles of root system grew each season and about the same amount died each year, leaving the soil porous and adding the decaying roots as humus. The roots for this study were washed free from the soil with extreme care. An example of this important work made a most attractive educational exhibit at the Atlantic City (1936) meeting of the American Association for the Advancement of Science.

Plowing and cultivation keep the soil loose. Worms greatly aid cultivation by making burrows through which

air and water can enter the soil. Darwin believed that the common earthworms brought soil up from their burrows and deposited it on the surface in such large quantities that sidewalks have been buried.

The degree of acidity may influence the texture of the soil, but acidity is more commonly considered in relation to the requirements of various plants. It is spoken of as the hydrogen (H) ion or pH of the soil and refers to the proportional number of free H-ions (which are responsible for the acid reaction). For general purposes we might make three groups of plants: those requiring strongly acid soil (azalea); those requiring nearly neutral soil (legumes); and the third group, between the extremes, but usually less exacting, with a slightly acid requirement (grass and most garden plants).

Soil can be readily tested for these three degrees of acidity by inexpensive devices to indicate acidity by color. With some study and experience it is quite possible to judge the acidity by the kinds of plants that grow best; for example where moss and sheep sorrel grow in the lawn, lime should be applied. Iron is insoluble in an alkaline soil, which may restrict the plant's absorption of that element. Liming an acid soil may set free a certain amount of potassium, exchanging it for the calcium, so that, liming may supply the plant indirectly with potassium as well as calcium.

Soil texture might include the dust mulch on the surface. The value of any mulch (dust, straw, or sand) is largely the retardation of evaporation and retention of a loose soil surface, as an aid to absorption of air and rainfall. A good mulch will prevent at least half the water loss from the soil by direct evaporation, which is often enough to save a crop. A dust mulch is valuable because it breaks the films of capillary water which tend to move to the soil surface. The more nearly all the films are broken the better the mulch. Shallow frequent cultivation both maintains a good mulch and destroys weeds. A black paper has been put on the market to

take the place of a mulch. It increases the temperature of the soil, prevents the growth of weeds, and retards to a high degree the evaporation of soil moisture.

Hoeing or cultivating soil is a common practice, but many experiments have failed to give evidence that it is valuable. It appears to have no merit in a direct way, but when done properly increases the absorption of rainfall, increases the aeration of the soil, destroys weeds, and probably increases the bacterial action in the soil. All this can be accomplished with a good mulch of grass, leaves, or other materials applied over the loose soil, in which case there is no need to hoe. If cultivating or hoeing is deep enough to destroy many roots the objection is obvious.

The water-holding power of the soil can be improved, even though it depends largely on the size of the soil particles. In a small flower bed it may sometimes be desirable to add sand to a heavy clay soil or to add clay to a sandy soil. It is usually easier, however, to improve a heavy or a light sandy soil by adding humus. The humus has a high water-holding capacity and it will increase the bacteria and animal population, both of which will aid in increasing the water-holding capacity. There are probably few cases where the water-holding capacity is too great and in such cases good aeration should overcome any difficulty.

Most plants require a well-drained soil; one in which the roots will not be immersed in water. Areas which are not drained naturally should have underground drainage in the form of tile about three feet below the surface. Drainage often increases the available soil water for plants by increasing the root depth, and makes the soil more porous. Roses, for example, which failed before drainage, may grow perfectly after drainage.

Humus includes all stages of decaying organisms (plant and animal) in the soil. In most soils the humus is largely of plant origin because the lignified cell walls decompose very

slowly. The value of humus to a soil can scarcely be overestimated because it improves the soil in so many ways. The addition of humus to a soil is one of the surest ways to improve it. Decaying humus adds mineral salts and nitrogen-carrying amino acids. It improves the physical condition by making the soil looser and increasing the water-holding capacity and the aeration.

Plants respond to applications of animal manures which cannot be explained by the above, and, in fact, has never been clearly determined. It has been suggested that the micro-organisms of the soil may be aided by manure and that the free-living nitrogen-fixing bacteria (*Azotobacter*) may increase the nitrogen supply to the plants. Recently it has been found to supply certain hormones which may be very important.

Humus is a constituent of all soils but it accumulates very slowly under favorable conditions. Heavy annual applications of manure adds humus only slowly. Best results are had by its slow natural addition to the soil. It is very easy to destroy the humus by excessive cultivation or by the loss of the top soil through erosion.

Humus is one of the most important factors in soil conservation. Cultivation increases the rate of decomposition of humus, which decreases the absorption of rainfall, thereby increasing the amount of the soil carried away. Both types of humus loss have taken place from many farm soils, where cultivated crops predominated, with the loss in productivity becoming so great that the farms have been abandoned. The rotation of crops in which humus-adding crops are used in place of cultivated ones has been helpful for their influence on erosion.

Compost, an artificial humus, is made, usually, by mixing plant material, sand, a high phosphate fertilizer, and sometimes manure, in a pile to decompose for a year or more. It is a means for a gardener who has the space, to make use of

refuse plant material and have an almost perfect soil for all kinds of garden planting. It is an especially desirable soil for planting seeds, if the seedlings must be transplanted.

The living organisms in the soil are numerous, but, fortunately most of them are beneficial. The harmful ones, in most cases, belong to the group of insects that live in the atmosphere and lay eggs in the soil. These develop into larvae of various sorts in the soil. The Japanese beetle belongs in this class and damages roots of grass or other plants. These can be destroyed by poison sprays on the leaves they eat, or by fumigating, or by poisoning the soil. If the soil is poorly aerated, bacteria which can change nitrates and set the nitrogen free may increase in number. This is discussed in more detail in Chapter 23.

The beneficial organisms should always be encouraged by the proper cultural methods. Nature will maintain a balance of organisms and the food for them. Therefore if we add organic matter and keep the soil aerated the organisms will increase in numbers. Many of the bacteria play a part in making nitrogen available to the plants, as explained under the topic of the nitrogen cycle in Chapter 23.

Soil erosion has destroyed many millions of acres of farm land and has reduced the yields of millions more. The problem is of less importance to gardeners than to farmers but if we are soil-erosion conscious we shall see many soil-covered sidewalks and many little gullies at the edges. Such unsightly conditions indicate the loss of at least three valuable constituents: water, soil, and mineral salts. The loss may not be great but in most cases the remedy is equally simple: prevent the run-off. If the garden has a slope of more than 4 per cent, Government soil erosion literature should be consulted.

The National Soil Conservation Service has found a number of ways to prevent run-off. Most astonishing is the fact that the rate, and therefore the amount of percolation is

several times as fast for clear water as for muddy water. Since the soil is porous clear water will enter rapidly but the silt of muddy water clogs the pores and makes the soil impervious. The rain water becomes muddy when the drops hit the bare soil, but if they hit vegetation which breaks them into a fine spray they will not disturb the soil. A good lawn is almost perfect in this respect because of the porous soil and the covering of both growing grass and a mulch of the lawn clippings. This should prevent run-off except in the winter and when the rainfall reaches cloudburst proportions. Soil erosion experiments have shown that a pasture may retain 90 per cent of the rainfall with no loss of soil while a like area in cultivation may retain only 50 per cent of the rainfall, and many tons of soil may be carried from an acre each year. Water run-off and the loss of soil depend on the amount of vegetative cover, on the rate and amount of rainfall, on the kind of soil, and on the slope.

The slope is important because it influences the length of time the water will stand on the soil in order to allow for percolation. If the slope is greater than 6 per cent it should be terraced, if that is practical, in order to have a high percentage of the area nearly level. If the terraces can be built as contours the water may be carried from one terrace to the next at the ends with a minimum of fall.

If a part of the area is cultivated, it should be done in strips with lawn between the strips. If this practice is followed the muddy water of the cultivated area will flow into the grass and lose its mud. This practice is recommended to farmers under the term strip-cropping.

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Chapter Twenty-Two

FERTILIZERS

Plants absorb some of each of the elements found in the soil solution, without regard to their need; in fact, poisonous ones may be absorbed in quantities sufficient to kill the plant. This subject will be discussed first from the point of view of soil culture and later in the more specialized water culture. Boron (an essential element) has been absorbed in amounts injurious to the plant. For example, at one time it became a serious problem when a small amount as an impurity in one of the fertilizer constituents caused tomato flowers to drop, with a considerable loss to the growers. Selenium (an unessential element available in certain soils) may be absorbed not only in large enough amounts to be toxic to some plants, but also, which is more important, in quantities which are not toxic to the plants but are sufficient to cause serious injury to animals feeding on selenium-contaminated plants.

Of the more than forty elements found by analyzing plants only fourteen are known to be essential for their growth. Some of these are needed in quantities of less than one-tenth of an ounce in a ton of dry matter, yet without this small amount the plants can not grow and produce seeds.

The fourteen elements may be divided into two groups. Three of the elements, carbon, hydrogen, and oxygen make up most of the plant (more than 98 per cent in corn), and they are obtained from the air and water, as described in Chapter 12. The other eleven elements, nitrogen, phosphorus, potassium, calcium, magnesium, iron, sulphur, manganese, boron, zinc, and copper are obtained from the supply in the soil. Except for nitrogen these eleven elements may be recovered from the plant ash.

Since such small amounts of the mineral elements are used by growing plants, the research in this field has been long and exacting. Most of these studies have been made by growing plants in water to which the various elements are added. Only recently manganese, boron, zinc, and copper have been added to the list of essential elements and other studies are in progress with other elements. This problem has been studied for several centuries as illustrated by the work of Van Helmont (1577-1644), who grew a sixty-nine-pound willow tree from a sprout in a weighed tub of soil, and when he found a loss of only two ounces in weight of the soil, he concluded that plants were made entirely of air and water, a mistake for which we must not censure him too severely.

Of the eleven elements supplied by the soil, only the first four, nitrogen, phosphorus, potassium, and calcium, are commonly added as fertilizer, since the last seven are needed in such small amounts by the plant, that enough is available in most soils to supply the needs of the plant. Probably no one has analyzed the chemical composition of strictly garden plants so completely as Latshaw and Miller have analyzed corn, but the results would be comparable. They found about 1 pound of nitrogen in 225 pounds of corn plant and much smaller amounts of each of the other elements; in fact they found nitrogen was almost equal in amount to the total of the other ten necessary elements. Since nitrogen is used in such large amounts in plant growth and is the one element that can be added by certain bacteria found in the soil and by leguminous plants, the next chapter has been devoted to this one element.

The chemical composition of plants varies widely depending on several factors, four of which will be described: (1) Newton found that the characteristics of plants vary in their absorption of elements when grown under the same conditions as shown by the composition of some common plants, as follows:

<i>Plant</i>	<i>Percentage of the dry weight of</i>				
	Ca	K	Mg	N	P
Sunflower	2.2	5.0	0.64	3.6	0.56
Beans	2.1	4.0	0.59	3.6	0.55
Wheat	0.8	6.7	0.41	4.5	0.49
Barley	1.9	6.9	0.54	4.7	0.52
Peas	1.6	5.3	0.50	4.5	0.19
Corn	0.5	3.9	0.40	2.9	0.39

Note that the peas have three times as much calcium as corn, more potassium and magnesium, nearly twice as much nitrogen but only one-half as much phosphorus. Other comparisons in the table are equally striking. (2) Carolus showed that the absorption depends on the availability of the elements. He found that when nitrogen and phosphorus were applied to the soil, the plants absorbed not only more of these elements, but also more calcium and magnesium. (3) Absorption of salts is increased by an optimum soil moisture content. (4) A reaction of the soil with a pH (see p. 171) of about 6 produces the best growth for most garden vegetables with a minimum percentage of mineral salts. These facts indicate that more consideration should be given to the conditions of growth in the selection of our vegetables as sources of mineral foods.

Fertilizers are applied to soils to supplement the deficient soluble elements of the soil. It must be remembered that the soil contains an enormous store of insoluble elements which are slowly becoming soluble. The fifty-year fertilizer experiment at the Pennsylvania State College Experiment Station shows clearly the stability of the soil. After forty years of cropping without fertilizer the yields had fallen to half the original, but if only phosphorus was added, in addition to lime to reduce the acidity, the yield was maintained for fifty years, showing that all the other elements were supplied by the soil. With the best treatment, namely, added phosphorus, lime, potassium, and nitrogen, soil described as in good state of fertility at the beginning of the experiment

showed an increase in yield of more than 30 per cent at the end of fifty years.

The stability of the soil was demonstrated in a different way at the English Rothamsted Experiment Station. Wheat was grown without fertilizer application for many years on the same soil, with a gradual reduction of yield, but after the field was fallow for two years the yield was restored. It may be assumed that the elements were gradually becoming available during the two years and were sufficient to produce a good crop. The one good crop, however, reduced the soil to its former infertile condition. It has been said that the average soil has enough of the essential elements to supply crops for hundreds of years if they were all available.

Since a chemical analysis of a soil will show the soluble and varying amounts of the insoluble elements it is clear that the result would not indicate the fertilizer needs. The best quick method is one in which a color reaction is used to indicate in a general way the available amount of each element. With this information and the knowledge of the previous treatment of the soil, fertilizers can be applied most efficiently. Several such "Soil Testing Sets" are on the market, but considerable practice is necessary before they can be used successfully. It is often better to write your State Experiment Station for directions for collecting a soil sample and have them make the tests. Recent methods have been devised to make tests of the growing plant tissues for the elements most likely to be deficient. This method is best where a continuous check on the needs of the plant is made.

So many different conditions of the soil and environment exist that it is often wise to experiment with various fertilizer applications on small areas of the lawn and on several different garden plants. Valuable information regarding the amount and the particular kind of fertilizer best suited to a local situation can be determined. If one, three, and five pounds of fertilizer per hundred square feet of lawn are ap-

plied on small adjoining areas in the fall you are almost sure to see differences during the following summer. Other experiments will suggest themselves. When crops are grown in rows, the treatment can be varied in much the same way, as well as in varying the relative amounts of the different elements. One can even omit nitrogen, potassium, or phosphorus from some of the plants. The results should be judged by the yield and by the characteristics of color, leaf size, and stem growth. If possible certain areas should have normal or no treatment for comparison as checks, with any type of experiment. The tabulation on page 169 should be consulted. Garden soils are seldom so deficient in any element as to show clearly the deficiencies described in the table, but the contents of artificial solutions made by adding salts to water can be accurately controlled. This experiment may be carried out by growing the plants directly in the water solution or by growing them in washed sand to which the water solution is added.

The photographs of buckwheat and cowpeas (Plates XI and XII) show the results of simple experiments in deficiency symptoms. Plants grown in clean sand with solutions added are compared with those grown in soil as checks. Color photographs of deficiencies are often shown in magazine advertisements for fertilizers. In performing either of these experiments a solution is made with ten of the eleven essential elements. The plant will be able to grow normally until it has used the supply of the omitted element from the seed and from the impurities of the other salts. Because of the difficulty of getting pure salts, plants grown in solutions lacking boron, zinc, and other elements used in very small quantities show deficiencies barely detectable. Those grown in solutions lacking nitrogen and other elements required in larger amounts show a growth proportional to the amount used in the plant and the amount stored in the seed. The cowpeas lost their leaves sooner without nitrogen. A small

difference in the purity of the salts will show in the results of certain experiments. The soil grown check plants had a dry weight equivalent to the full nutrient plants in these experiments. It is of interest to note that the plants grew appreciably better with tap water than with distilled. This shows the unusual dilution, as found in tap water, from which salts can be absorbed.

A TABULATION OF THE CHIEF FUNCTIONS AND GENERAL SYMPTOMS OF DEFICIENCIES OF THE ELEMENTS TAKEN FROM THE SOIL

<i>Element</i>	<i>Functions in the Plant</i>	<i>Symptoms of a Deficiency</i>
Nitrogen	Constituent of protein, protoplasm, and chlorophyll molecules. Excess produces large plants.	Small plant. Yellow-green color of leaves.
Phosphorus	Constituent of nuclear protein. Improves root growth and seed formation. Aids in enzyme actions.	Poor root growth. Bluish-green leaf color. Shorter internodes.
Potassium	Essential for photosynthesis and sugar translocation. Improves quality of fruit.	Stunted growth. Premature death. Small chlorotic leaf spots.
Calcium	Aids in absorption of other elements and in root growth.	Poor root growth. Buds and young stems stunted.
Magnesium	Constituent of chlorophyll. Necessary for formation and use of oils.	Chlorotic rusty spotting of older leaves.
Iron	Essential for synthesis of chlorophyll.	Lack of chlorophyll and poor root growth.
Sulphur	Constituent of protein. Aids nodule formation in clovers.	Poor root system and vigor. Resembles plants low in nitrogen.
Manganese	Used in oxidation process and chlorophyll synthesis.	Chlorotic leaves and death of the youngest ones.
Boron	Necessary for cell division.	Young buds and leaves become brittle and break off easily.
Zinc	Not clear.	May cause "little leaf" and "white bud" diseases.
Copper	Not clear.	At least some plants fail to grow seed.

Fertilizers are usually purchased with a guaranteed percentage analysis of available nitrogen, phosphorus, and potassium. These three elements together are called a complete fertilizer, and are expressed as a 4-12-4 fertilizer, when

4 per cent of nitrogen, 12 per cent of phosphoric acid, and 4 per cent of potash are present. This is a good general purpose proportion of elements for much of the eastern United States, but many other combinations are available as well as incomplete fertilizers, containing one or two elements. If a large leafy plant is desired a much higher proportion of nitrogen may be used. The analysis above shows only twenty pounds per hundred of available plant food, but it must be remembered that part of the other eighty pounds will become available gradually.

The most successful method of fertilization over a long period is the application of manure and a phosphorus fertilizer. The photograph (Plate XIII) shows the importance of higher amounts of phosphorus on root growth and deep color of the tops, since they improve from the smaller to the larger amounts. In the lower series the influence of varying amounts of nitrogen is shown. The reverse response in root growth is seen; but the tops are larger with higher nitrogen. The phosphorus and the manure make the most desirable combination of elements for most soils. The manure is often difficult to procure and to apply on the lawn, and besides it has many weed seeds. The use of three pounds per one hundred square feet of a complete fertilizer, in the late fall and again a month before active growth begins in the spring, on the lawn and the perennials will make a wonderful improvement in growth. The garden areas that are dug and cultivated should have a like application before planting and two more at about twenty-day intervals when hoeing. It has been found that plants require large amounts of fertilizers when they are making their early growth and relatively small amounts as they mature. It is possible to use too much fertilizer, but this happens only rarely. It must be mixed with the soil, or, if put on the lawn, followed by a copious watering to carry it to the soil. In this way it becomes incorporated with the soil and can be absorbed by the plant.

Soils slowly become acid because plants remove a little more of the alkaline than of the acid elements, and the alkaline elements leach from the soil more rapidly, leaving acid residues in both cases. The balance of alkaline to acid elements is referred to as pH which means the ratio of hydrogen ions (acid) to the alkaline or basic ones. A pH of 7 means that they are in equal amount and neutralize each other. When acid ions increase to ten times as many in proportion to the basic ones the pH is 6 and when alkaline ions increase to ten times as many in proportion to acid ones, the pH is 8.

A few plants, such as the azaleas, rhododendrons, most ferns, and orchids, are adapted to an acid soil of a pH ion concentration of 5.0 or lower. Those plants that naturally grow in an oak or evergreen forest are likely to grow better when the soil is kept acid. Soils may be made more acid by aluminum or ammonium sulphate. In the former the aluminum becomes insoluble and in the latter the ammonia is absorbed by the plant, leaving the sulphate part as an acid in the soil.

Most plants grow best when the soil is only slightly acid, as explained in Chapter 21. Lime, in any one of three forms, may be used to neutralize the soil acids; as finely ground limestone, calcium carbonate (CaCO_3), as the burned limestone or quick lime called calcium oxide (CaO), or as the hydrated lime ($\text{Ca}(\text{OH})_2$) where one molecule of water unites with a molecule of the calcium oxide. The ground limestone although slow in its reaction is a little more convenient to handle. The hydrated form is commonly used. Most lime contains some magnesium, but it should not exceed 14 per cent, since it is toxic in excessive amounts.

Calcium, like phosphorus, has been found recently to diffuse very slowly through the soil while the other elements diffuse more rapidly. In order to have accessible to a large part of the root system a favorable supply of the calcium and phosphorus it is best to mix large amounts of it with at least

the top foot of soil when preparing permanent areas for lawn or perennials. A ton of ground limestone and a ton of finely ground phosphate rock per acre may be used. Ground bone meal may be used to supply the phosphorus and to add a part of the calcium. Opinion differs regarding the frequency of applying lime, but it is safe to be guided by the change in the pH. Plants thrive in a range of one pH or more, that is, for most garden plants a favorable range goes from 5.6 to above 7 pH.

In the more specialized technique mineral salts have been used in water solutions for many years for growing plants in experiments like the one explained in this chapter, but recently the method has been modified for use in commercial greenhouse culture, where it is believed that, at least under some circumstances, it is more economical than the use of soil. Flowers and vegetables grown by this method, called "hydroponics," are available now in many markets. Many people are using this method of growing plants as a hobby, but to be successful it requires a close study of the technique and should be attempted only by those who are willing to be disappointed at first. When the techniques have been mastered it is a most efficient and satisfactory way to grow large yields of excellent plants.

Several water-culture systems have been devised, and often named for the man or institution making them popular. "Soilless Gardening" by Gericke uses the water solution, in shallow tanks or troughs, with the plants supported in a seedbed of vegetable material on a wire support. The seedbed and an air space between it and the solution are the distinctive features of the method, which provides for root aeration, the most difficult problem. The seedbed has a layer of straw or excelsior on the wire, then a layer of finer vegetative material, which will support the plant, hold moisture to be absorbed by the roots growing in it, and allow air to pass through it freely to the air-space below. The air-

space may be only an inch for young plants, but is allowed to increase as the young plants grow. The book "Soilless Gardening" must be consulted for the formula and the many details of the system.

Dr. J. W. Shive, at the New Jersey Agricultural Experiment Station, devised various ways of bubbling air into the solution without the use of the seedbed. The bubbles are best if they are very small. Ordinary fish aquaria aerators seem to be satisfactory.

A third method, which is very simple to operate, employs sand as a medium for the roots, and the nutrient solution is dripped on the top and allowed to drain away at the bottom. This insures good aeration if the sand is of the proper coarseness to allow the water to drain through freely.

Simultaneously workers at the Agricultural Experiment Stations of Purdue University and New Jersey devised a fourth method, used commercially quite frequently, employing a fine gravel or cinders in place of the sand. The gravel is too coarse for water to move rapidly by capillarity, therefore the gravel is flooded two or more times each day to keep it wet and allowed to drain back to a storage tank. The solution is kept in a tank beneath the gravel plant beds, and electric pumps, controlled by time clock switches, work automatically. This method gives the maximum of aeration and for large installations a minimum of labor. The solutions are tested two or three times each week and supplied with needed elements.

The writer made use of methods one, three, and four in the greenhouse with very simple, inexpensive equipment, as shown in the photograph (Plate XIV). Tomatoes, buckwheat, and corn all grew to maturity, the latter with a height of more than ten feet. Two problems—the nitrogen was too abundant and the pH too high—offered some difficulty, but both were later regulated satisfactorily. The pH must be kept below 6.5 if the solution is warm, to keep the iron in

solution. The gravel was flooded by a simple automatic device requiring attention about every day. It depends on slow drip from a supply bottle, and an automatic siphon to carry the solution to a bottle below when it reaches the flooded stage. The siphon is shown at the end of the gravel tank.

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Chapter Twenty-Three

NITROGEN

Nitrogen is so important in the growth of plants that a complete chapter is given to its discussion. It is a large important part of the living material of the plant protoplasm and of the storage protein. As shown by the photographs (Plates XI and XII) its complete absence from the soil solution retards growth as much as though the plant were deprived of all salts; in fact, it might be called the limiting element.

Most soils are deficient in nitrogen and, therefore, its application brings a quick response in growth and improved color of the leaves. These pleasing results tempt the gardener to overstimulate with nitrogen and so to produce a plant with larger cells, longer internodes, larger leaves and a smaller root system (Plate XIII). Nitrogen should be applied most heavily in the early stages of germination of a plant to encourage rapid growth, and in decreasing amounts later in the season in order that as it ages the plant will develop sturdy structure and will store larger amounts of food material. Plants so treated are less likely to winter kill than others and are able to use the stored food for rapid growth the next season.

The carbon to nitrogen ratio was discussed at some length in Chapter 14. The idea of ratio should be kept in mind in dealing with any phase of the nitrogen problem. The plant can be kept considerably *off* a balanced carbon and nitrogen ratio to produce a desired type of growth. All the methods for controlling the ratio may be used, but certainly it is influenced most by the pruning, the amount of sunlight, the soil moisture, and the applications of nitrogen.

The description of the relation of growth to nitrogen supply should be read in Chapter 14. It has been found that, regardless of light, plants can build proteins in any actively growing cell that has an adequate supply of carbohydrates and nitrogen. Normally the nitrogen content of the soil decreases during the summer, which causes a deficiency in the plant resulting in carbohydrate storage. If a high nitrogenous fertilizer is applied in mid-summer or early fall the plants may respond with a rapid growth which will not harden or mature enough to avoid winter-killing.

The root systems of plants with high nitrogen are smaller in proportion to the tops when compared with those from better-balanced nitrogen-level plants (Plate XIII). For this reason high nitrogen plants will suffer more quickly from drought. A simple experiment to study the root effect of nitrogen may be made by using plants in pots and treating with varying amounts of nitrogen as described above. A garden experiment would be better if the removal of the roots is not too great a task.

A study of the influence of growth and storage of carbohydrates may be made by keeping a high nitrogen level with roses by heavy pruning through the summer or by adding nitrogen to the soil at frequent intervals. Normally high nitrogen will stimulate excessive new growth until late fall. The new growth will not be hardened resulting in more winter-killing, and the following summer the growth may be poorer because of the lack of stored food.

Nitrogen is commonly applied as nitrate of soda or as ammonium sulphate. The sodium leaves a more alkaline medium and the sulphur a more acid one. Acid-loving plants should have the latter, but if it is used on other plants it will be necessary to use lime more frequently. Ammonium nitrate may be used, in which case the nitrogen is available from both the acid and alkaline radicle. The nitrogen cycle diagram shows that plants are able to use either the am-

monium nitrogen or the nitrate nitrogen. Some plants appear to have a preference, but in many cases it depends on the conditions of the soil. Most garden plants can use the nitrate form better with a pH of 6.5 or lower, but above this pH in some cases they use the ammonia form more effectively. Nitrogen is often applied in an organic form as bone meal, tankage, cotton seed meal, or raw bone meal. These forms act slowly because they are not available until they are decomposed by bacteria as shown in the chart (Fig. 25). Manure carries some nitrogen and, as explained above, it appears to stimulate the nitrogen-fixing bacteria.

A lawn will need very small applications of nitrogen, since the high organic content left by decaying roots furnishes food for the nitrogen-fixing bacteria, and also the lawn holds moisture so well that the leaching effect is reduced. If nitrogen is applied it should be done in the fall or in the early spring before the shoots begin their active growth. At this time the soil is low in nitrogen and growth may be limited.

The size of flowers can be increased with nitrogen, since it reacts on flowers in much the same way as on leaves. Leafy vegetables can be increased in size with nitrogen. The nitrogen content of the soil is usually lowest after protracted heavy rains in mid-summer or later, when it may become so low that the plant reacts as indicated by lack of good green color.

The problem of an adequate supply by nature of nitrogen salts for the soil is not understood. The atmosphere contains 79 per cent of free nitrogen but plants cannot use it until it is fixed in a molecule. The salts of nitrogen are very soluble and are readily leached from the soil. In fact under some conditions as much may leach from the soil as is used by the plants. A crop of corn may use more than a hundred pounds of nitrogen per acre, whereas the farmer seldom applies more than fifteen pounds per acre as fertilizer. Each crop except the legumes, which bear nodules on their roots containing

nitrogen-fixing bacteria, removes more nitrogen from the soil than is applied as fertilizer. The legumes include the clovers, vetches, beans, peas, lupins, etc., all of which develop small ball-like nodules on their roots if the proper bacteria are in the soil. A single strain of bacteria will inoculate several but not all species of clovers. Another strain is necessary for lupins and a third for alfalfa.

If the proper bacteria are not in the soil they must be added to the seed or the soil. These symbiotic bacteria can

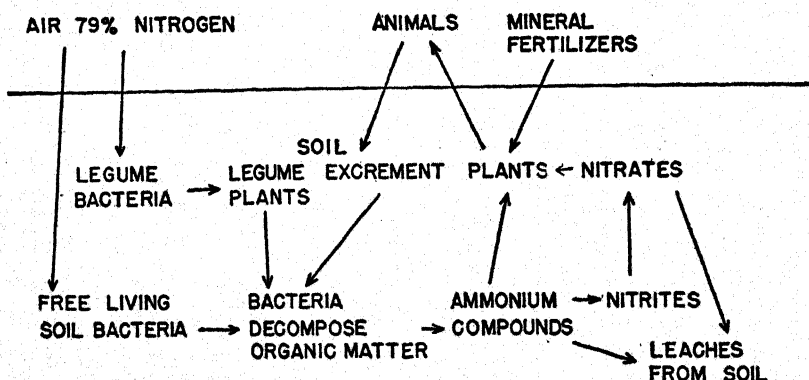


FIG. 25. The nitrogen cycle. Nitrogen from the air may be traced by the arrows as it is acted upon by various bacteria until it can be used by plants. The plants may be eaten by animals or they may be decomposed by bacteria.

convert free nitrogen from the air into a molecule which can be used by the legume, and when the legume is decomposed by other bacteria the molecular nitrogen remains in the soil. This and the later described bacterial action are shown in the nitrogen cycle (Fig. 25) which should be consulted as a guide to the whole problem.

A legume crop removed for hay will not add so much nitrogen to the soil as the corn crop uses. Thus crops remove more nitrogen from the soil than is added by man, and leaching may lose a like amount. A small amount is washed from the atmosphere as ammonia by rains.

Two sources may explain the problem of the additional supply: first, the work of the free-living nitrogen-fixing bac-

teria, and second, the bacterial action which liberates the nitrogen of dead plants and animals.

The various species of bacteria and their numbers, far beyond the concept of man, must remain in a kind of balance because of their dependence on each other. Without this great group of microscopic organisms, agriculture, as we know it, would be impossible. The fact is more startling when we realize that so little is known about the various bacteria involved and that no general attempt is made to maintain the most desirable balance.

The nitrogen-fixing bacteria that live in the soil have been difficult to study but several groups are known to use humus as a source of energy and are then able to fix atmospheric nitrogen (use free nitrogen and convert it into a usable molecule containing nitrogen). The soil must be aerated since the one group must have oxygen for their respiration. *Azotobacter* and *Clostridium* are two groups of nitrogen-fixing bacteria, but detailed studies of their activities are difficult since the soil is so complex a medium that the factors cannot be controlled and they probably do not react the same in sterile condition in a test tube as they do in the soil. It is believed that part of the value derived from manure or other forms of humus is due to the increased activity of the nitrogen-fixing bacteria. It is quite possible that these bacteria add more nitrogen to the soil than do the legume bacteria in the ordinary farm rotation but in gardening practice the legumes find little use.

The bacterial action of decay and the preparation of that nitrogen for plant use involves several groups of bacteria. Bacteria which cause decay of other bacteria, plants, or animal excrement, change the proteins to amino acids and then to ammonia. This forms ammonium compounds in the soil. As explained above and shown in the chart the ammonium compounds may be used by the plant, but if not, they are acted on by other bacteria which oxidize them in order to get

energy. The first group of bacteria oxidizes the ammonia to a nitrite form, after which another kind of bacteria oxidizes the nitrite to nitrate. This nitrate is absorbed by the plant just as effectively as that applied as fertilizer to supplement the soil supply.

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Chapter Twenty-Four

SOME SPECIAL CONSIDERATIONS OF PLANT GROWTH

Growth is an irreversible change in shape or weight of a living organism. It usually means an increase in dry weight because of the increase in cell number and size, but in case of seedling growth the weight decreases (see table below) because the stored food is being oxidized. Growth is the result of many coordinated activities of the organism, some of which are deeply involved in growth regulators and stimulants. Some of our knowledge of hormones in relation to growth is briefly described in Chapter 20.

The germination in soil of radish and pea seedlings in full sunlight, in 10 per cent full sunlight, and in darkness (Plate XV) shows the external influence of light on growth. The following table tells the story of the use of the food (in dry weight) and the relative amounts of water in the green weights:

<i>Light</i>	<i>Green wt. gm. per plant</i>	<i>Dry wt. gm. per plant</i>	<i>% of gain or loss in germination</i>
		Radish	
Full	0.206	0.016	45 gain
10 %	0.212	0.010	19 loss
Darkness	0.328	0.007	37 loss
		Pea	
Full	2.252	0.221	32 loss
10 %	2.499	0.203	38 loss
Darkness	3.274	0.196	40 loss

The leaves are thicker, the roots are better branched, and the shoots are much shorter, with full sunlight. Shade has little effect on the size of the leaves, but makes a marked increase in stem growth, and a decrease in dry weight. The dark-grown plants show the lack of leaf growth, the extreme

growth of the stems, and an extreme loss of dry weight. Growth hormones may be inactivated in the light. The radish in full sunlight carried on photosynthesis to more than regain all the loss in the early germination, but the pea has regained only a small amount of the earlier loss. Most plants should not be transplanted until the seedlings have regained a supply of stored food.

Growth is often defined to include all the activities in the development of the plant, including: cell division (see Chapter 4), synthesis of protoplasm, elongation of the cells, differentiation of the cells, and the final maturing of the cells for their special functions. The synthesis of the protoplasm and cell walls requires food as the building material and oxygen for respiration. The elongation of the cells depends on the osmotic concentration and turgor pressure against the walls and on the growth-regulating hormone. The cellulose cell walls must stretch and the growth hormone appears to regulate the resistance to stretching. A comparison of the green weights and the dry weights under these different conditions of light, as well as the size and the shape as shown in the photograph, illustrates how these water and growth relations are manifest in seedlings when they are influenced by varying amounts of light.

Available water also influences growth in size and in dry weight. When water is deficient growth will be reduced because of a decreased turgor pressure and a relatively smaller increase in green weight than in dry weight will be found. Under drought conditions the stomata may close as explained in Chapter 13, causing a further decrease in the rate of growth in size and in dry weight because of the retarded photosynthesis.

Since the turgor pressure is so important it is evident that it will be greater at night because of the decreased transpiration and that growth (stretching) will be greater than in the day. This can readily be determined by night and morning

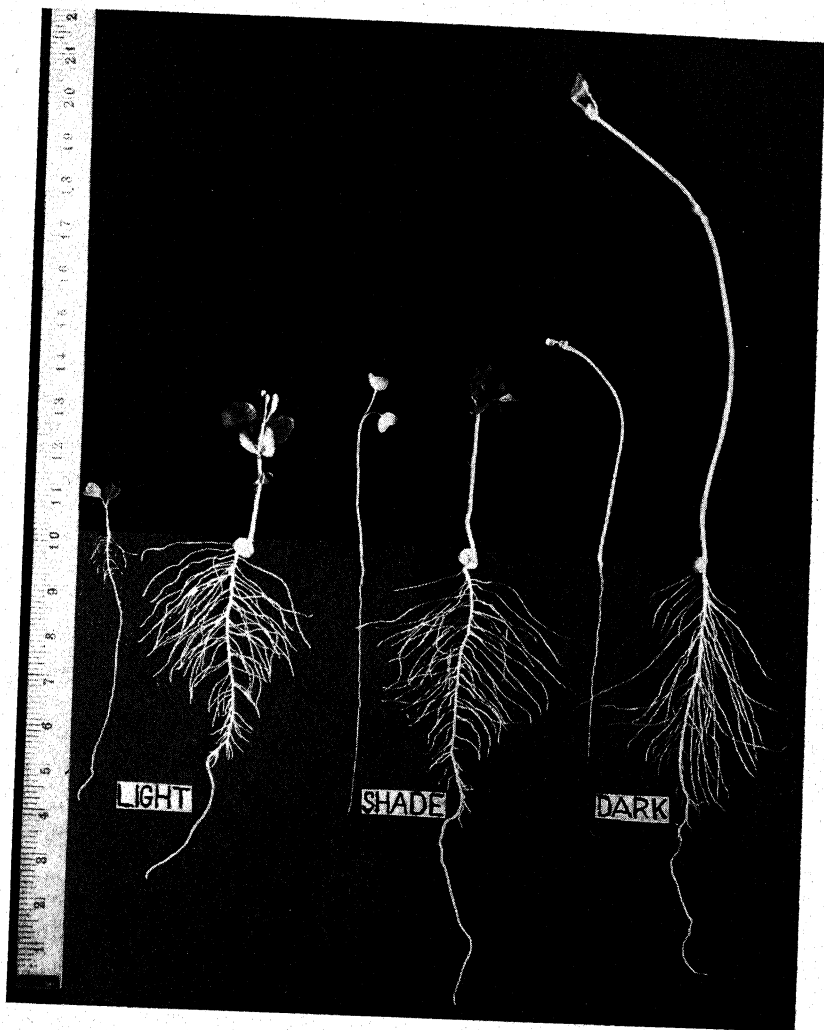


PLATE XV. Seedlings grown in sunlight, in shade (10% of sunlight), and in darkness. Radish (left); pea (right). ($\frac{1}{4}$ natural size.)



PLATE XVI. Growth of morning-glory and moonflower in soil with optimum moisture (left) and low moisture (center).

measurements of a rapidly growing plant. Growth is not related to photosynthesis, except for the food supply which is normally in excess of the immediate needs.

Inasmuch as all cells of an organism come from the original fertilized egg and since all newly divided cells are similar, it is obvious that cells must differentiate to form the many kinds of tissues in an organism. This change from the original kind of cell must be controlled by hormones or organizers but it is not understood. Finally the cells take on their matured characters, as the wood cells with thick lignified walls or the thin cell walls of the pith or any one of the many forms of cells in the leaves.

The rate of growth is variable depending on the conditions that influence growth. Normally a cell, an organ, or complete organism, such as a plant or animal, begins to grow slowly, but increases the rate for some time, following which the rate remains high for a time and then declines. It is not uniform but rhythmic. This is true of a shoot or of one side of a shoot or of a pollen tube or a fruit. This rhythm is best shown by time-lapse motion pictures.

The rate of growth is influenced by temperature. The lowest or minimum temperature for growth is about freezing. As the temperature increases the growth rate increases to about 90° F., beyond which it decreases for most plants. Many plants that have been studied may grow rapidly for a few hours at a high temperature after which the rate decreases, but if the temperature decreases for a time, growth increases again with an increase in temperature. This may be a night and day response.

Many plants have a decreasing growth rate as the temperature increases above 90°, and may stop growing at about one hundred ten degrees. Plants can withstand higher temperatures and will resume growth when conditions become favorable. The transpiration of plants reduces their temperature; therefore, if plants are killed by naturally high

temperatures in this region it is usually because of lack of moisture.

Plants can be conditioned to endure low temperature. It is called "hardening" and is brought about by decreasing the water supply and subjecting them to progressively lower temperatures alternating with higher ones. The temperature is often alternated at 36° and 50° F. then gradually lowered. Cold injury is usually due to a lack of water in the whole plant or in some of the cells of the plant. Transpiration will go on at a reduced rate in cold weather while absorption is retarded considerably, especially if the ground is frozen. When cells freeze the water begins to freeze and as the water freezes more is withdrawn from the protoplasm. This may continue until the protoplasm has its water reduced to the point where it is injured. Frequently slow thawing enables the protoplasm to regain the water without injury. Hardened plant cells have a higher colloid and sugar content which resists the loss of water and may explain the value of the hardening process. Plants that normally remain in the soil during the winter should be kept cold to keep them dormant, since they withstand cold better in a dormant condition. Mulching should be done when the ground is frozen.

Water constitutes from two-thirds to more than 95 per cent of living, growing plants. Any deficiency of water first reduces the turgor pressure of the cells and may in extreme cases be so limited that the protoplasm will not be elaborated. The elaboration of protoplasm and enlarging of the cells, due to water absorption, are not synonymous but it is difficult if not impossible to measure them independently. The explanation for the rapid growth of plants with water culture solution rests on the adequate supply of water at all times. Methods of watering plants were discussed in Chapter 13.

The writer's interest in the water relation of plants led to greenhouse experiments on the influence of soil moisture on growth. Morning glory and moonvine plants were grown

in four-gallon crocks of soil with a known moisture content. The crocks were weighed frequently and water was added to maintain: in the first crock, the optimum amount; in the second, the minimum amount that would support continuous growth; in a third, the optimum was kept for the first half of the growth period and the minimum for the second half; and in the fourth crock, the first half was grown at a minimum and the second half at the optimum moisture. Only the first and second conditions will be explained. The photograph shows in general the nature of the growth and the bottles for adding the water. The plants with optimum water reached a length of ten feet and were trained along the roof of the greenhouse but are hanging down to the crock in the photograph (Plate XVI). The plants with minimum moisture were less than one-fourth as long. The dry weight of the tops and the surface area of the leaves had the same relative relationship. The number of the stomata did not follow so clearly the one to four relation. The plants with optimum moisture had about ninety thousand stomata per square inch and those with minimum moisture about a third more. It is generally believed that plants growing where moisture is limited have fewer stomata, as was true here on a per plant basis, but they actually have more of them in a given area. This has been found to be true on other plants. If the increased size of the leaves with the moist soil is considered the number per leaf and per plant is much greater than with the dryer soil. The humidity of the air also must have a marked influence on growth but no careful experimental work with this condition is known to the writer.

Perhaps next to temperature and water supply, the supply of food, both as minerals from the soil and as carbohydrates of photosynthesis, is most important in growth regulation. Second only to water the food supply is modified with greater ease and more striking results in the average garden than the other growth factors. Experiments of interest will suggest themselves to many gardeners. Each of us

has tried, or has heard of our friends trying, the chemical vitamin B₁, as a growth stimulant. The importance of a soil with a texture loose enough to supply oxygen to the roots must be included here and a reference to other growth-regulating conditions described in earlier chapters.

Plants grow in cycles or at certain periods, alternating with periods of rest or dormancy, as is commonly observed in the spring after the winter dormancy. This is one of the hereditary characteristics. It is true for the shoot and for the root, although the first period of root growth begins before shoots elongate and the leaves grow in the spring and a second period occurs in many plants in the fall. The growth in stem thickness may be more variable depending on the growth conditions but normally the stem thickens more rapidly during the spring growing period. Flowering cycles in some plants depend on length of day rather than time of year or the age of the plant. Any experimental work should be planned to coincide with the normal growth cycle.

It is possible in many cases to modify the growth cycle, but that at once becomes an experiment of major importance. The reader may refer to some of the work of F. E. Denny and his co-workers, reported in the contributions of the Boyce Thompson Institute, for the details of the treatments. Gardeners make use of natural growth cycles in following the periods of planting, pruning, and harvesting the desired crop.

One of the most striking and interesting illustrations of changing the normal growth cycle was announced by the Russians a few years ago concerning wheat. Normally sown in the fall, winter wheat grows a small plant before winter puts it in a dormant condition. The next spring's long days induce heading and ripening. "Vernalization" is the term applied to forcing plants to go through a part of their life cycle in an unusual controlled method. The treatment of wheat consists in giving a mass or pile of it about half the maximum amount of water it can absorb, and hold-

ing it at a temperature of about 60° F. for twenty-four hours to start germination. Next the temperature is lowered to about freezing for about two weeks. This prepares the grain to begin normal growth in the spring, after which it can be dried and kept until the soil is in condition for seeding. It would appear that the same growth reactions take place with this treatment that take place in fall-sown wheat. The Russians claim extensive use of this method of growing wheat. They believe vernalization can be applied to many other plants in many other ways.

To illustrate in another way, plants requiring short days and warm soil may be given just enough moisture to allow some—it is not clear which—physiological activities to go on for a week or longer, but only enough to make little or no growth, while at the warm temperature of the summer and in the dark. This, the Russian investigator, Lysenko, says gives the plant its needed amount of warmth and darkness for development, and it will be able to grow to maturity with lower temperature and longer days than it requires when planted untreated. Time will be necessary to test these methods under many conditions and to simplify the procedure.

The rapid growth of many plants in the far north with continuous daylight indicates that at least some plants can make food and grow efficiently under what in industry we would call twenty-four-hour shifts. The great question remains, can we learn to control the many enzymes, hormones, and growth regulators in an artificial manner to speed up the growth of plants in an environment where they do not naturally grow?

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Chapter Twenty-Five

REST PERIOD OF PLANTS

Most plants of the temperate zones have developed the characteristic of growing only during the summer. Annuals grow, bear flowers, seeds, reach old age, and die during the summer. The embryo plant of the seed is the only part or stage to have a rest period. At the end of the growing season biennials and perennials go into a dormant or rest period for varying lengths of time, part of which is usually during the winter. The physiology of these adaptations to climate are not understood. The rest period is that time during which a plant or any part of a plant remains dormant or inactive even though it is given all the external conditions necessary for growth, and should be distinguished from the inactive period of stored seeds, due to unfavorable conditions for germination. Most plants, bulbs, tubers, seeds, etc., can be kept in an inactive condition after the rest period is past, by subjecting them to a low temperature and keeping them with a low moisture content. Either a low temperature or a low moisture is often sufficient but both are better.

Dormant and inactive plants carry on all the activities necessary for life, but at a very low rate. Several thousand bushels of wheat may be kept in storage for months with no thought of its oxygen supply, but the small loss in weight indicates very slow respiration. Dormant seeds usually have more stored food and less water but the water is held more securely in the colloidal mass. The cells are mature, growth has ceased, and the rate of respiration is very low. These conditions enable a plant or seed to withstand extremes of temperature which would be impossible with actively growing parts. This characteristic is most striking among wild

plants, where the seeds may be matured in early summer and lie unprotected in a dormant condition until the following spring or in some cases for a much longer time. The rosette stage, frequently on a fleshy root, developed by a biennial remains dormant over winter and grows a tall shoot with seeds the next summer, as in carrot (Fig. 18). Perennials remain dormant in winter but grow and produce seeds each summer. This characteristic rest period is so deeply fixed in oaks that the seedlings grown in the greenhouse for four years continued to lose their leaves and remained dormant during the winter but their leaves commenced to grow each spring only about two weeks before those of the oak trees outside the greenhouse.

Dormancy is more deeply fixed in certain species than in others but in all cases it appears to be stronger in the early period and appears to weaken as the period progresses. Toward the end of the period it is easily broken in most plants. Bulbs, tubers, seeds, and branches of flowering shrubs may be forced in most cases by treating with warmth of 30° to 35° C. for twelve to twenty-four hours, if treated near the end of their dormancy, but more drastic treatment would be required at an earlier period.

The dormant period is not always in the winter; crocus, tulip, spring beauty, and many other bulbous plants begin the dormant period in late spring and begin root growth in the late fall or in mid-winter. The bearded iris has a period just after flowering that approaches a dormant condition. All bulbs and rhizomes may be transplanted most effectively during the dormant period.

The seeds of many of our cultivated plants have a very short or no dormant period. Grapefruit seeds are often germinated in the fruit. Beans and peas may sprout in the pod if it falls on the ground. The farmer uses care in shocking his grain to prevent its getting wet enough to cause it to sprout before it is dry enough to put in storage. Some spe-

cies have a short dormancy. White oak acorns which can be seen germinating almost immediately after they fall, while closely related species, black or red oak acorns, under the same conditions, remain dormant until early spring.

Most of the seeds of the clover family have a dormant period. Freshly hand-hulled sweet clover or alfalfa seed has about 90 per cent of dormant seeds. They remain dormant because a band of impervious matter in the seed-coat prevents the entrance of water. These seeds are usually treated in some manner to crack or remove the impervious layer before planting, which causes about 90 per cent to germinate at once. This treatment is called "scarification." In other seeds the seed-coat may prevent the entrance of oxygen to the embryo as in the common cocklebur (*Xanthium*). A third condition, induced seed dormancy, is due to a tough seed-coat. The swelling embryo cannot break the coat as in case of the pigweed. Dormancy caused by the seed-coat can be overcome by filing or by rubbing it with an abrasive.

Other seeds remain dormant because of the condition of the embryo. The embryo may be immature and unable to germinate until it grows to a larger size. In other cases the embryo appears to be mature but it requires internal changes grouped under the heading of "after-ripening." These changes have been studied but in most cases are not understood. The breaking of this type of dormancy is more difficult than those caused by the seed-coat.

The physiology of dormancy indicates that it is due to some changes in those substances called growth regulators, which are in small amounts but have profound influences. In some plants a change in enzyme content occurs at the end of dormancy. In other plants it appears to be a growth hormone change. The change may be made in a branch or a single bud while the remainder of the plant is dormant.

Methods of breaking or overcoming the dormant period have been found without knowing the nature of the change.

Dormancy in bulbs is desirable while they are in storage and until they are planted. Near the end of their dormant period a very short exposure to a warm temperature may break it. In the earlier period of their dormancy alternate cold and warm is effective. Most dormant perennial plants and seeds will also have this resting period shortened in either of these two ways. Treatment with any one of a number of gases is effective with most plants and seeds. Ether, ethylene dichloride, ethylene chlorohydrin, carbon bisulphide, and others have been used.

Dormancy has been studied more in seeds than in other parts of plants, and in addition to treatments described above, most seeds have their dormancy shortened by a natural warm-cold treatment called "stratification." The seeds are mixed with peat, sand, or sawdust, kept moist, and put in the soil where the temperature will fluctuate between freezing and a few degrees above. This method is commonly followed also where incubators can be used to control the temperature at 1° C. to 5° C. Rose seeds may be planted in outdoor flats, where germination should be allowed to go on for at least twenty months with frequent examination to remove the seedlings. Some species of rose, as *multiflora*, germinate within four months in favorable conditions, but most species and hybrids require careful stratification and the longer period. Some seeds, such as bluegrass, and lettuce, have their germination hastened with light, and others, such as *Datura*, in the absence of light.

The rest or dormant period of plants is used constantly in gardening. We do the main pruning and transplanting of perennial plants during the dormant period. Plants store food and grow large root and shoot systems during the active period, and the food reserve that has been stored can be used for growing the new absorbing root system, and sending out a new set of leaves. The least damage is done in transplanting at the dormant period because of the reserve

food, the tissues are hardened, the fewest roots are killed, and the shoot withstands more drought.

The gardener who has so cared for the plants during their active period as to enable them to store large quantities of food will always be rewarded by the growth they make when they come out of the dormant period. Growth should be avoided for some time before the dormant period to allow the tissue to harden. Unless buds and branches are hardened, they readily winter-kill.

Even though plants withstand much greater extremes of temperature during the rest period those that are near their northern limit may need to be protected to avoid winter-killing. The best protection is provided during the previous summer by proper growth and food storage after which a moderately moist soil, and low transpiration should be maintained in the winter. A small mound of earth may give additional protection, but where more is needed, straw may be used if proper precaution against rodents is taken.

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GLOSSARY

Bacteria are microscopic one-celled plants, which may live as individuals or in groups called colonies, and which reproduce mainly by cell division.

The *cambium* is a cylinder in the plant just inside the true bark made of a single layer of cells which can divide to add cells to the bark on its outside and to the wood on its inside. It supplies the cells for the growth in thickness.

Chlorophyll is the complex chemical green pigment of plants.

A *chloroplast* is a small amount of specialized protoplasm which contains chlorophyll.

Chromatin is a protein compound found in the nucleus of a cell, which determines the characteristics of the organism.

Chromosome is a short thread-like structural unit of chromatin visible during the division of the cell.

A *clone* is a group of plants vegetatively propagated from the same parent.

The *coleoptile* is a tube or sheath covering the plumule of the grass-type seedling until it emerges from the soil, after which the coleoptile dies.

A *corm* is a shortened fleshy stem with leaves growing from the upper side and roots from the lower side, as in gladiolus.

The *cortex* is a group of thin-walled cells inside the epidermis with a variable function, but most frequently it stores food and in many cases has chlorophyll, hence it makes food.

Cross-pollination is the transfer of pollen from the anther of a flower to the stigma of a flower on another plant.

Cytology is the study of the internal structure of the cell, i.e., with chromosomes.

The *cytoplasm* is the living matter of a cell outside the nucleus. The nucleus and cytoplasm constitute the protoplasm of a cell.

Diffusion is the spontaneous intermingling of the molecules of two (or more) liquids or gases in combination, which results in an equal distribution of the molecules of each liquid or gas among those of the other. Diffusion is caused by the characteristic of all ions or molecules to go from regions of their respective greater concentrations.

A *dicotyledonous* plant is one which produces seeds with two seed leaves (cotyledons) such as the two fleshy bodies in a pea or bean seed.

The *embryo* is a many-celled early stage of an organism receiving food and protection from the parent. In the case of the plant it is the reproductive stage in the seed.

Endosperm is the stored food which develops independently of the embryo in an albuminous seed.

Enzymes hasten the chemical reactions of organisms without entering into their compounds (such as in the digestion of foods).

An *etiolated* plant is one with characteristics resulting from deficient light, i.e., less chlorophyll, larger cells, longer internodes and, in complete darkness, very small leaves.

Exalbuminous seeds are those in which the endosperm is not developed, but the stored food is in enlarged cotyledons.

Fertilization is (may refer to) (a) the application of plant food to the soil, or (b) to the union of the male sex cell with the egg cell or with the endosperm nuclei of the ovule.

Fungi form the group of simple non-green plants known as bacteria, molds, and toadstools.

A *gene* is the smallest unit of a chromosome which can determine a characteristic of an organism.

Heredity is the tendency of the offspring to be like the parents. It is based on the chromosome as the basis for the transmission of such tendency.

The *hilum* is the scar caused by the breaking of the seed from its attachment in the ovary.

Hormones are secretions of certain parts of an organism which are carried to other parts of the organism where they promote some special activity.

Humus is any decaying organism found in the soil. It usually gives the soil a darker color.

A *hybrid* is the offspring of two parents whose characteristics differ in one or more ways.

Hybridizing is the act of developing new plants by bringing in contact the sex cells of two unlike plants, i.e., cross-pollination.

The *hypocotyl* is that part of the seedling between the cotyledons, or seed leaves, and the root.

An *internode* is that portion of a stem between two nodes, or joints from which leaves and buds appear.

A *membrane* is a thin often invisible layer of cells or molecules separating two kinds or conditions of matter. (A surface-tension membrane separates the water molecules in a drop of water from the air.)

Meristematic cells are those which divide to form new cells, i.e., the cells in the cambium and the tips of stems and roots.

The *micropyle* is a small pore in the seed coat below the hilum through which the pollen tube enters the seed coat.

A *molecule* is the smallest particle of any compound, i.e., H_2O , or $C_6H_{12}O_6$.

Monocotyledonous seeds have a single seed leaf, i.e., in the embryo of corn, Figure 1.

Mutations are sudden changes or variations in organisms caused by changes in the chromatin and therefore are transmitted by all later cell divisions.

Mycorrhiza is a symbiotic fungus which grows on the outside in the form of a mantle and into the root either between the cells or into the cells, of many plants, chiefly the woody types.

A *node* is the part of a stem from which one or more leaves and buds grow.

The *nucleus* is the part of a cell containing the chromatin of the cell. It appears to have certain special functions necessary to the life of the cell.

Osmosis is the diffusion of molecules through a membrane. In the plant the membrane is one of cytoplasm inside the cell wall.

The *ovary* is the basal portion of the female organ of a flower in which the seeds will grow.

The *pericycle* is a layer of cells in stems and roots between the phloem and the cortex.

The *petiole* is the stem-like structure of a leaf by which it is attached to the stem.

The *phloem* is a group of elongated cells, usually outside the cambium, which conducts food material.

Photosynthesis is the making of sugar by the use of the energy from light, using water and carbon dioxide as the raw materials. This can take place only in the presence of active chlorophyll.

Plumule is that small portion of the embryo of the seed which develops into the shoot of the plant.

Polyploidy refers to multiples of the normal number of chromosomes for a given species.

To *propagate* means to multiply or increase the number of organisms.

The *protoplasm* is the living matter of a cell, consisting of the nucleus and the cytoplasm.

The *radicle* is that part of the embryo of a seed which becomes or develops as the root of the seedling.

The *stele* is the conducting portion of a root including the xylem, phloem, cambium, and pericycle. It is surrounded by the endodermis and cortex.

Stipules are the two appendages at the base of most leaves. They are of various forms, but frequently are small bract-like structures.

The *stoma* is an opening through the epidermis of a leaf between two guard cells through which the gases pass, i.e., carbon dioxide, oxygen, and water.

Symbiosis is the living together of two kinds of organisms in such a way that each is benefited.

Transpiration is the evaporation in the leaf and loss of moisture from a plant to the atmosphere.

Vacuole is a space or cavity in the protoplasm of a cell containing other matter, i.e., the cell sap.

Variation is a change in the characteristics of the offspring from those of the parent. It is usually the result of the environment during growth or of a new combination of the chromatin at the time of the fertilization of the egg cell.

The *xylem* is the water conducting portion of a plant made of elongated cells, which generally become woody as they get older.

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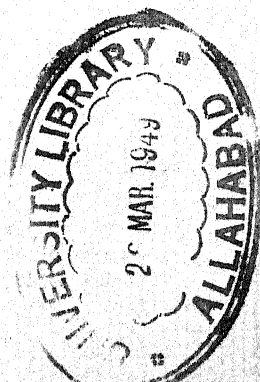
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